CLASS-BOOK

OF

ELEMENTARY MECHANICS.

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OF

ELEMENTARY MECHANICS.

An Introduction to Natural Philosophy.

ADAPTED TO

THE REQUIREMENTS OF THE REVISED NEW CODE.

PART I.—MATTER.

BY

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PREFACE.

SOME three years ago the Liverpool School Board resolved to introduce experimental science teaching into their schools, and the writer was appointed to organise a scheme of demonstrations in accordance with this resolution. The subject selected for demonstration in the boys' schools was elementary Natural Philosophy, or Mechanics as defined in Schedule IV. of the Revised Code. The experience gained in the practical carrying out of that scheme has led to the production of the present work. It is primarily intended as a lesson book to be used by the scholars in the intervals between the experimental demonstrations. The difficulty hitherto has been to get the children to express, in anything like precise language, the ideas which the experiments have suggested to their minds. It is hoped that a careful reading of the following lessons week by week, supplemented by the comments and explanations of the teacher, may go a long way towards removing this difficulty The exercises at the end of each lesson are believed to constitute a valuable feature of the book if properly used. They deal for the most part with practical applications of the principles set forth in the preceding lesson, and have been specially designed to stimulate the observing and reasoning faculties of the scholars. Each exercise, in fact, might furnish a theme for conversation between a teacher and his class. It is universally acknowledged that education of this kind, where the scholars themselves are made to do the main part of the work, the teacher guiding their efforts and occasionally assisting them, is the best education in the true sense of the word.

Although the book has been arranged to accompany a special series of demonstrations, it is also adapted for use as a class-book in any school where the subject is taught. It would be a very easy matter for an intelligent teacher to devise numerous simple experiments, in addition to those incidentally referred to in the book, to illustrate each lesson. A very small outlay would provide all that was really necessary in the way of apparatus, and indeed a vast number of illustrations and experiments might be shown by the aid of such simple objects as are to be found in any house or schoolroom.

The present part deals with MATTER, and embraces the subjects of the first stage of Mechanics as defined by the Revised Code. A second part, dealing with FORCE, and embracing the second and third stages of the subject, is in preparation.

W. H.

LIVERPOOL, *April* 1880.

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CLASS-BOOK OF ELEMENTARY MECHANICS.

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LESSON 1.

MATTER.

That which we can perceive by our senses to exist is called "matter." Substance, and thing, are words sometimes used instead of matter.

We are provided with five senses, *i.e.*, five means of finding out something about the substances by which we are surrounded. These senses are termed **sight, smell, taste, touch,** and **hearing.** By the sense of sight, for example, we ascertain that the sun is bright, that leaves are green, and that water is transparent. By the sense of smell, we perceive that there is a difference between ammonia and water, though to the sense of sight both are alike. By means of the sense of taste, we are able to class some substances as sweet, others as bitter, and others again as sour, &c. The sense of touch enables us to distinguish between rough and smooth substances, and to ascertain whether the edge of a knife is sharp or blunt. The sense of hearing sometimes informs us that the wind is blowing, (*i.e.*, that the substance we call air is in motion), and that the waves are dashing on the beach.

Let us suppose that we enter a room into which coal-gas is escaping. We become aware of the presence of that particular kind of matter, in the first instance, probably, by the sense of smell. We discover the exact place where it is escaping, perhaps by hearing a slight hissing noise. We make sure of it by holding our hand over the hole, so as to feel the current (or wind) of gas. And possibly we make one more experiment to satisfy ourselves that it is really coal-gas, by cautiously putting a light to it, to see if it will burn.

Each substance has certain characters or **properties,** by which we can distinguish it from other substances; and these properties we ascertain by the use of our senses. Thus a marble has the properties of roundness, smoothness, greyness (or some other colour), incombustibility, &c. In order to describe a substance, we mention some of its most important properties.

All kinds of matter have several properties in common, of which three of the most important are these,—**extension, divisibility, weight.** By saying that any portion of matter has **extension,** is simply meant that it takes up some room, *i.e.*, extends over a certain space. By **divisibility** is meant the property of being divided; and no one has yet seen a piece of matter so small that it cannot possibly be divided into still smaller pieces. A drop of water on the point of a needle, is large enough to contain thousands of very small animals swimming about in it. A small lump of sugar put into a large pail full of water is broken up into pieces too small to be seen, and some of it is present in the smallest drop of water we can take out of the pail. **Weight** is a property which we shall consider in a future lesson; for the present, it will be sufficient to know that when we say a body has the property of weight, we mean that it presses down towards the earth. With a good balance, and with care, every substance that we are acquainted with can be weighed, even such substances as the air and coal-gas which are invisible. There are other properties common to all matter, with which we shall become acquainted as we proceed with these lessons.

We have learned that our senses inform us of the existence of matter, and that there are many different kinds of matter; each kind possessing certain properties. Some of these properties we can ascertain by observation alone, others can only be discovered by experiment, that is by doing certain things to make these properties plain and apparent.

EXERCISES.

1. What properties of glass can be ascertained by the sense of sight, touch, and taste respectively?
2. By what properties may coal-gas be distinguished from air?
3. What are the properties of iron and of copper respectively?
4. Name three bodies to illustrate each one of the following properties:—(1) transparency; (2) sweetness; (3) redness; (4) smoothness; (5) roundness; (6) brittleness.
5. Describe the properties of a good knife.

LESSON 2.

THE THREE STATES OF MATTER.

In the preceding lesson, we learned that there were many different kinds of matter, distinguishable by their properties; for example, red matter, green matter, sweet matter, &c. We soon learn, however, to group together all these different kinds of matter into three great classes, which we call respectively solids, liquids, and gases. **Matter occurs in three states or conditions, viz., in the condition of a solid, a liquid, or a gas.**

In the solid state, the parts of which a portion of matter consists are relatively fixed, and therefore the solid retains its shape if left to itself.

In the liquid state the parts are not fixed, but can move about among themselves; the shape changes according to the shape of the vessel which contains the liquid. Hence it is necessary to support a liquid round the sides, otherwise it will flow or spread out into a thin sheet.

A gas is still more changeable than a liquid, since, if not prevented by being enclosed on every side, it will spread out, or flow, in every direction. A gas will take not only any shape, but also any size.

We can state the distinction between these three states of matter very shortly, by saying that **a solid retains both its size and its shape : a liquid retains its size, but will change its shape : a gas will change both its size and its shape.**

Some kinds of matter are occasionally found assuming each of these three states. Thus water is usually met with in the form of a liquid, which must be enclosed round the sides by a vessel, if we wish to retain it in any particular shape and place. Cold, however, changes liquid water into the solid which we call ice, in which the parts are so firmly held together that we see it lying about in lumps. Heat effects another change, for it converts liquid water into the gas which we call steam. The same is true of solid butter and other kinds of fat, which are converted by heat into liquids. It appears, therefore, that the particular state in which we find a certain portion of matter at any time, depends altogether on the temperature or degree of heat.

Liquids and gases have many important properties in common, and are sometimes classed together under the one name **fluids.** This term is applied to them because they will flow, that is, will spread out of themselves, if not supported round the sides. The great difference, however, between them is this, that while it is very difficult to alter the size of a liquid, even a little, a small quantity of gas will fill out a very large space, and a large quantity of gas can readily be forced into a very small space.

EXERCISES.

1. Name ten solids, ten liquids, and as many gases as you can.
2. Name ten fluids. Explain the meaning of the term fluid.
3. Mention several substances which are sometimes liquids and sometimes solids. What causes them to change from solids into liquids?
4. State the properties of ice which distinguish it from water.
5. The water of the sea rises into the air in the form of vapour, and usually descends again in the form of rain or snow. Explain the causes which thus change the state of the water.

LESSON 3.

SOLIDS.

Matter, as we have seen, may take one or other of three forms, viz., the solid, liquid, or gaseous form, and we have learned somewhat of the differences which exist between these forms. We must next take each form by itself, and study its characters.

The particles (or very small parts) of which we know every solid body is composed, are held together by some power or **force**, and to this force the name of **cohesion** has been given. In most solids this cohesion is strong, as we find when we try to separate one portion of a solid from another. But its strength varies in different solids, for it is much easier to tear apart a thin wire of lead, than a wire of steel of the same thickness. And in many solids the force of cohesion varies, according as we try to break the solid in various ways. A strip of glass, for example, would support a heavy weight hung from it lengthwise, while it would snap across at once if we tried to bend it. Substances like glass, which readily snap when we try to bend them, are said to be **brittle**. Substances which can be bent in various ways without breaking, are said to be **tough.** Were it not for cohesion, there would be no such thing as a solid body ; matter would be broken up into the smallest possible pieces. Most of the other properties which belong specially to solids, are due to the fact that **in solid bodies generally the cohesion is strong.**

There is one other fact about cohesion in solids which is very interesting, viz., that when once the cohesion is destroyed, as by powdering the solid, it cannot easily be restored. A drop of water can be divided into two or more drops, and these when brought together again will at once unite to form one large drop as at first. The powder of broken glass will not unite again, even though pressed together very strongly ; and the cohesion can only be restored by melting the solid, *i.e.*, by first turning it into a liquid. And this is the case with most, if not all solids.

A solid body retains its shape if left to itself, and does not need to be supported round the sides as a liquid does. The shape of a solid can be altered more or less by pressure on it, and some solids are so soft that they can be moulded into any shape. Lead is a familiar example of such solids ; sponge, bread, clay, and putty are other examples. It is easy to understand why sponge and bread can have their shape so easily changed, since, besides being soft, they are porous, that is, full of small holes or **pores.** Clay and putty again are moulded so easily, because they really consist of fine powders mixed with a liquid, viz., water in one case, and oil in the other. A powder is a collection of very small solids.

The size of a solid body is definite or fixed, so long as the body is not acted on by any great force. But by the action of a powerful force, all solid bodies can be slightly compressed, or forced into a smaller space. As a general rule, we must remember that **solids are difficult to be compressed, and can only be compressed very little.**

If a block of wood rest on a table, and between the wood and the table a sheet of paper be placed, the paper will of course be pressed down by the wood. If now a weight be set on the top of the wood, the paper will be pressed down still more, for the pressure of the weight is carried through the wood, or the wood is said to **transmit** the pressure. If a second piece of paper rested against the side of the wood, the pressure of the weight would have no effect on this piece of paper, for the wood transmits the pressure only in one direction. And this is one of the most important properties of solids, that **they transmit pressure, but only in one direction,** viz., the direction in which the pressure acts on them. To take one more example of this important property: if some one were to push against one side of a table, the effect of the push would be felt at the opposite side, but not in any other part of the table.

A number of solids together, especially if they are small and round as marbles or shot,—or better still, if they form fine powder as sand or flour, — transmit pressure in a somewhat different manner from that in which one solid does. In a bag of flour or a bag of sand, we may see that there is great pressure not only on the bottom, but also on the sides of the bag. And if we set a weight on the bag, or press on it with our hands, we may see that the pressure is transmitted laterally, as well as in a straight line. When we come to consider liquids, we shall see that they also transmit pressure laterally, but much more perfectly than these masses of small solids.

EXERCISES.

1. When is a body said to be brittle? Name several brittle bodies, and several bodies which have the quality opposite to brittleness.
2. Explain why you can put your finger into sand, and not into a piece of iron.
3. Why does a paper bag containing flour often burst at the sides?
4. Define the words *cohesion*, *transmission*, *laterally*, *compression*.
5. Name two very important differences between solids and liquids.
6. If a piece of iron were ground into fine powder, how could the cohesion be restored, so as to form the whole into one solid lump of iron?

LESSON 4.

STRUCTURE OF SOLIDS.

A piece of sugar, or a drop of water, is built up of a vast number of very small portions, or particles, and it is for this reason that we are able to divide each of those bodies. As we expressed the fact in a former lesson, these bodies, in common with all others, have the property of divisibility. The smallest portion of sugar, or of water, which could possibly be obtained, is called a **molecule,** which really means a little piece. And the same is the case with all other solids, and with liquids and gases. We may therefore make this general statement :—**All bodies are built up of molecules.** In the course of these lessons, we shall frequently have to speak of the molecules of which bodies are composed. If we understand clearly this idea of the constitution of matter, we shall find that we are able to explain many facts, which would otherwise be very difficult to explain.

When we come to examine the manner in which solids are built up, we find great differences in various solids. And as this is a very important matter in many respects, we must examine it somewhat in detail. If we take a quantity of the solid known as alum and crush it into powder, we shall find on putting some of this powder into a quantity of cold water, that all or part of it will dissolve and disappear in the liquid. Having dissolved as much alum as possible in the water while cold, if we then heat it, we shall find that the water will dissolve a still further quantity. If the hot water be saturated with alum—*i.e.*, made to dissolve as much alum as possible—and be then poured out into a saucer or other vessel and set aside to cool, a further observation may be made. As the water cools, a portion of the alum will separate from it in the form of a solid substance, or rather in the form of many solids, which are small at first but gradually increase in size. Examination of these solids soon reveals the fact, that they are all more or less of one shape, viz., a four-sided pyramid, or perhaps like two ordinary pyramids attached by their bases (fig. 1).

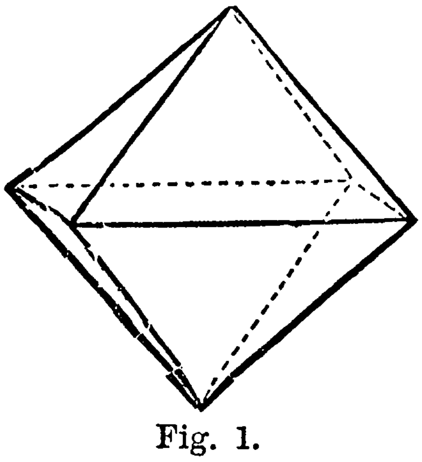

Fig. 1.

And further, however dirty the solution may be, these solids, at any rate while they are small, will be found clean, almost transparent, with bright smooth faces and sharp edges. Such bodies are called **crystals,** and the alum is said to be **crystallised.**

Many other bodies behave in a similar manner, separating from the liquid in which they have been dissolved in the form of crystals. The crystals of the other substances would not be of the same shape as those of alum, each different substance having a more or less different form of crystal. But they would agree with the alum crystals in having smooth shining faces, sharp edges, and in being, as a rule, nearly pure. Crystallised sugar, sugar candy, and saltpetre are familiar examples of crystallised bodies. A large number of crystals of different substances are found in caves, in mines, in crevices of rocks, &c., and some of these have been formed from solution, like the crystals of alum. In museums we may see examples of many of these crystallised minerals, such as gold, diamonds, quartz or rock crystal, sulphur, several kinds of "spar," and the ores of many metals. Very beautiful substances they usually are, and well worth looking at carefully. So constant is the form of each particular mineral, that experienced persons are able to distinguish one mineral from another by its form alone.

The bottom of the vessel containing the alum solution, if left for a day or two, will be found covered with a cake of alum, from which cake, on its upper surface, project parts of crystals. But in the great mass of it the crystals are so entangled together, that it is almost, if not quite, impossible to distinguish one crystal from another. Bodies which are evidently composed of crystals, but in which the crystals are not easily distinguishable, owing to their being so mixed up with each other, are said to be **crystalline.** Marble and loaf sugar are good examples of crystalline bodies. The small sparkling faces which are seen in these substances are faces of crystals, but the crystals are all so matted together, that none have had the opportunity of growing large and distinct.

When a substance is dissolved, its molecules are separated from each other by the action of the liquid, and being so small are invisible. In many cases, as the liquid cools, or as it is slowly evaporated, cohesion draws these separated molecules together again, forming them into one or more solids. The molecules, however, do not come together in any order or position, but fit into each other so orderly and neatly, as to build up the regularly formed body which we term a crystal. So that **a crystal may be said to be a solid having a regular form, and composed of molecules which are arranged in a definite order.** Two important consequences follow from this, the first of which is, that since particles of dirt or other substances would not fit properly in the building up of the crystal, these are usually left behind in the liquid, and the crystals are obtained almost pure. And if they are dissolved and crystallised again several times, they will at last be obtained quite pure. Common washing soda is crystallised, to separate it from the dirty substances which become mixed with it in the process of manufacture; and most of the solid substances sold by druggists are crystallised in order to purify them. The second consequence is, that a crystal will cut or split more easily in some directions than in others; just as it is easy to drive a nail into the side of a wall between the bricks, while it would be extremely difficult to drive it down into the wall from the top. The molecules in a crystal correspond to the bricks in the wall; and a crystallised substance differs from an uncrystallised one, just in the same manner as a neatly-built wall differs from a confused heap of bricks. The men who have to cut diamonds and other precious stones into various shapes, take advantage of this property of cleavage or splitting, and always endeavour to arrange their work so as to cut the mineral in the easiest direction.

There is another way in which crystals of some substances may be formed, viz., by first melting the substance so as to turn it into a liquid, and then allowing it to cool slowly. In this way crystals of sulphur and some metals are formed.

Snow consists of small crystals of solid water, or ice, which often have most beautiful shapes (fig. 2). These can be seen very distinctly by observing some snowflakes, caught on a dark surface—say a black coat—during a snow-storm.

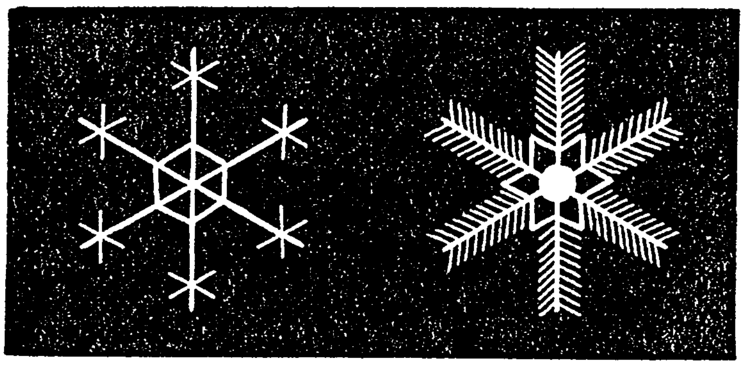
Fig. 2.

Substances like clay, putty, butter, and lead, which can be cut as easily in one direction as in another, and which do not under ordinary circumstances take any definite shape, are called **amorphous** or shapeless bodies.

There are other names used in addition to those already mentioned, in describing the structure of solids. Thus, solids which can readily be split into splinters, threads, or fibres, are called **fibrous** solids, and of these we have examples in wood, rhubarb, and lean meat. Paper is a fibrous body, and is seen under the microscope to consist of a number of small fibres crossing each other in all directions. When a piece of paper, such as that used for blotting paper, is torn, these fibres may be seen at the torn edges.

Another term sometimes applied to certain solids is **granular,** which means composed of grains, or small rounded pieces. Sandstone is a rock composed of grains of sand, and is therefore said to be granular.

EXERCISES.

1. What is a crystal? Name a number of common substances which are crystallised.
2. What is the advantage of crystallising solids?
3. Sketch the form of a crystal of alum, and of sugar.
4. Explain why wood will split more easily in one direction than in another.
5. In what way does the arrangement of the fibres differ in the following fibrous substances—paper, rope, calico?

LESSON 5.

HARDNESS OF SOLIDS.

We can, without any difficulty, plunge our finger into water or other liquids, because the cohesion is so small that the parts readily separate to allow our finger to pass between them. But on attempting to penetrate a piece of stone in a similar manner, we meet with a great resistance, owing to the greater cohesion of the solid stone. We usually express this fact by saying that the stone is **hard.** Certain solids yield somewhat to the finger, and are dinted, as india-rubber, or easily penetrated, as butter, and these we distinguish as **soft.** Different solids have various degrees of hardness, as we should expect after having learned that the force of cohesion varies so much among them. A better way of testing the hardness of a solid than to push it with our finger, is to take a sharp edged, or sharp pointed, instrument, such as our finger nail, or a knife, or a pen, and endeavour to cut or scratch the body. If with a steel knife we can cut the "blacklead" and the wood of a pencil, and if neither wood nor blacklead will cut, or even scratch, steel, it is plain that steel must be harder than either of those two substances. Similarly, if we can scratch lead with our finger nail, and if lead will not scratch our nail, it must be that our finger nail is harder than lead. Once more, glass is generally spoken of as a hard substance; but when we find that a diamond will not only scratch glass, but that, if the diamond be of the proper shape, it will cut deeply into the glass, we must allow that diamond is harder than glass. In this manner, then, we can test the hardness of one solid, as compared with that of other solids. Now it has been found, that while a diamond will scratch any other solid whatever, no solid that we know of will scratch a diamond. Therefore it is said that a diamond is the hardest of all solids. This is a point of practical importance, for the men whose business it is to cut and polish diamonds for jewellery, know that the only substance they can use for polishing a diamond, is the dust obtained from other diamonds. A diamond, after it has once been polished, will remain smooth and bright, much longer than a piece of glass or other substance made to imitate it, since it may rub against many substances without being scratched at all. And diamonds have of late been made use of, on account of their excessive hardness, to bore through hard rocks.

The substance which stands next to diamond in hardness is emery, which is much used for grinding and polishing steel, glass, and other hard substances. Emery cloth, as it is called, is made by scattering powdered emery over strong calico, which has previously been covered with glue. It is used for cleaning rusty steel, and for other similar purposes.

But the substance which is of most importance to us on account of its hardness is steel, and of this nearly all our cutting instruments are made. Steel is a variety of iron, which has the wonderful property of becoming hard or soft, according to the way in which it is treated by the workman. If a piece of steel be made red hot, and then allowed to cool slowly, it will become comparatively soft, so soft that it is not very difficult to bend it, and far too soft to be of any use for knives, or scissors, or chisels. The same piece of steel, however, can be readily made hard, by again heating it, and when hot plunging it into water, or oil, or other liquid, so as to cool it very quickly. The degree of hardness which the steel acquires, depends upon the quality of the steel, the temperature to which it is first raised, and the rapidity with which it is cooled. Saws, chisels, knives, &c., are made into their proper shapes while in a soft state, and are then hardened in the manner just described. The workmen vary the degree of hardness given to the different instruments, according to the use to which they are to be put. We ought to observe that steel becomes brittle, at the same time that it becomes hard. We may, therefore, sometimes have to choose between having our tools very hard and very brittle, or moderately hard and less likely to break should they happen to fall. It seems to be a general rule, that substances which are very hard are also very brittle.

Other metals cannot be hardened in the same manner as steel. Many can be hardened by mixing with them a small quantity of a different metal, or **alloying** them as it is called. It has to be ascertained by experiment, what metal is the most suitable to form the alloy in each case. Gold in its pure state is a soft metal, and if it were made into coins in that condition, these would very rapidly be worn thin. It is found necessary to harden the gold used for coinage and for jewellery, by alloying it with a little copper,—for our English coinage, 1 part of copper by weight is added to 11 parts of gold. For the same reason, silver is alloyed with copper before being made into money,—92½ parts of silver being alloyed with 7½ parts of copper.

Bronze pennies, half-pennies, and farthings, are harder, and therefore stand wear better, than the old-fashioned copper coins which they have replaced. They consist of an alloy of 95 parts of copper, 4 parts of tin, and 1 part of zinc. The very soft metal lead, which is so much used for making bullets, shot, types for printing, &c., is hardened by alloying it with a small proportion of another metal called antimony. Brass, which is an alloy of copper and zinc, is harder than either of those metals alone.

EXERCISES.

1. Arrange the following substances in the order of hardness—copper, glass, emery, iron, steel, lead, and diamond.
2. Explain clearly why it is found necessary to alloy gold with copper before being coined.
3. Describe and explain the use of sand-paper, or glass-paper.
4. Why is it better to make a ruler of ebony than of ordinary deal?

5. Why do uncivilised people use pieces of flint for cutting and scraping rather than pieces of wood.
6. Name several cutting and other tools made of hard steel, and describe a method by which they could be made less hard if required.

LESSON 6.

EFFECTS OF HEAT UPON SOLIDS.

We have now to study the changes in solid bodies, which are brought about by the action of heat. Perhaps the change which we most readily observe, is the softening which occurs in most bodies when heated. In the preceding lesson, we learned that the hardness of a solid body is due to its cohesion; when the body becomes softer, therefore, it must be on account of the cohesion becoming less. And we may readily prove that such is the case, by observing that we can easily cut through a stick of sealing-wax which has been softened by heat, or by observing the ease with which a blacksmith pierces or cuts a piece of red-hot iron. We shall find that it is a general rule, that **heat lessens the amount of cohesion in bodies.** A piece of wire, which will easily support a certain weight whilst at its ordinary temperature, will be broken by the force of the weight if the wire be heated. Some bodies, such as sealing-wax, become so soft when heated that they can be moulded into any shape; and what is more important, two pieces can be made to stick together quite firmly. Wrought-iron is another body which, when sufficiently heated, softens so much that it can be hammered (or wrought) into any shape, and two pieces can be hammered or **welded** firmly together.

If we go on increasing the degree of heat, the cohesion becomes at last so far lessened, that the molecules are no longer held fixed in their places. They are able to slide or move about among each other, they spread out round the sides if not held, and in fact the solid becomes converted into a liquid. In the second place, therefore, **heat liquefies or melts solids**, if it be sufficiently great. We know from experience, that all solids do not liquefy at the same temperature, that is, with the same degree of heat. Solid ice melts with the heat of a warm room, butter melts on a warm summer's day, sugar or lead may be melted in an iron spoon over the fire. Iron requires a much greater heat, which is obtained in a special kind of fireplace called a furnace; the bricks of which the furnace is built require a still greater heat to fuse or melt them. Of all the metals, mercury, or quicksilver as it is sometimes called, is the most easily melted, more easily than ice. So easily indeed is mercury melted, that in England we may leave it out of doors on the coldest day in winter, and it will remain a liquid. In colder climates than ours, mercury becomes a solid, and can be cut and hammered like a piece of lead. Tin, lead, and zinc, can be melted in an ordinary fire before even they become red hot: silver, copper, and gold require a very good fire indeed: iron requires a furnace with a good draught. There is one metal, called platinum, which will not melt in any fire or furnace, but requires the most intense heat which we can obtain, viz., that produced by electricity. There is a substance which is even more difficult than platinum to melt, for it is used to convey the electricity when we wish to obtain the electric light, and the heat sufficient to melt platinum; and although this substance is exposed to the full heat, it has never yet been melted. This substance we call charcoal or carbon. The chemist tells us that coal, graphite (or blacklead as it is usually called), and diamond, are all composed of this substance carbon, although they differ so much from each other in appearance and properties.

Heat produces a third change in solids, which is not so readily observed as the changes we have already mentioned. It is easily proved, however, that nearly every solid body when heated expands, or becomes larger. And this expansion takes place in every direction, the body becoming at the same time longer, broader, and thicker. Thus if we had an iron bar, which would when cold just reach from one wall of a room to the opposite wall, and just fit also into a hole of the same shape as itself, this bar when hot would be too long to lie down between the two walls, and too large to go into the hole. When the bar had cooled down again to the same temperature as at first, it would be found to have returned exactly to its original size. We can easily understand that if we put the bar in a very cold place, it would grow smaller every way, or would contract. In the third place, therefore, we say that **heat expands solid bodies, and cold contracts them.** A very few bodies are known which do not expand when heated, but we need not now trouble about them. These changes which occur in the size of a body are so very small, that people generally take no notice of them, but they are really very important. The more strongly bodies are heated, the more they expand. All bodies do not expand to the same amount, some expand much more than others; brass, for example, expands nearly twice as much as iron, if the two are equally heated. The iron bars of which a railway is formed are not laid close together, but a small space is left between the adjoining ends of each pair. We might observe that this space is less in summer than in winter, and occasionally, in hot weather, the rails expand so much that their ends meet together, and no space is left for any farther expansion in this direction. During very hot summers it sometimes happens that, after the rails have met in this manner, the heat tends to expand them still more. In such cases the rails become bent and twisted, in order to find room to expand, and that portion of railway becomes useless for a time. Iron bridges expand or contract with every change in the temperature of the air. And to prevent the bridge from becoming broken or bent out of shape, like the rails just mentioned, one end is not fastened down tight, but is frequently put on rollers, so that it may easily move backwards and forwards. For the same reason, one end of the firebars of a grate or furnace should be left free, in order that they may expand and contract. Drinking glasses are frequently cracked by pouring hot water into them, and the reason is very plain. The inside of the glass becomes heated and endeavours to expand, but the outside remains cool and of its original size, especially if the glass be thick, and consequently the struggle often ends in the glass being cracked. The iron rim, or tire, placed round wheels, is fitted on tightly while it is hot, then, as it cools, it draws together with enormous force the separate pieces of wood of which the wheel is built up, and they are held as if in a vice. A great many other examples might be given of the expansion and contraction of solid bodies by the action of heat and cold.

EXERCISES.

1. Why does a lump of clay become hard when put into a fire? What other changes will the clay undergo if the heat be sufficiently great?
2. In fastening two plates of iron together, the iron nails (or bolts) are often put in red hot; is there any advantage in doing this?
3. Describe the changes which take place in a piece of lead placed in an iron ladle over a good fire.
4. Why are the bars of fire grates made of iron rather than of zinc or lead?
5. When a glass stopper is very fast in the neck of a bottle, people sometimes slightly warm the bottle neck, and the stopper comes out easily. Explain this.
6. Arrange the following substances in the order in which they would melt, if exposed to heat—gold, ice, platinum, beeswax, iron, lead, butter.

LESSON 7.

PROPERTIES OF SOLIDS.

Solids are composed of very minute portions, each of which is called a molecule; these molecules are held together by the force of cohesion. In solids, this force is sufficiently strong to keep the molecules fixed in the same position in the body, that is to say, the molecules are not able to move about among each other. But the amount of cohesion varies in different solids, and frequently also in different directions in the same solid. Therefore, since the strength of any particular solid depends mainly on the strength of this cohesion, different solids have different degrees of strength. And since the molecules of a solid are so firmly fixed together, the solid retains any particular shape that we may give to it, without the necessity of supporting it, as we should have to do with a liquid. The size of a solid also remains the same, unless we use considerable force to alter it. By pressing with great force upon solids, doubtless they may all be compressed a little ; but in general it is difficult to compress a solid, and then the amount of compression is only small. Heat causes the molecules of a solid to move further apart from each other, and thus increases the size of the body as a whole, or expands it. Cold has exactly the opposite effect,—which is just what we should expect when we remember, that to cool a body is simply to take heat away from it. When we take heat away from a body, the cohesion gets more and more power over the molecules, and draws them closer together. Solids also become soft under the action of heat, and when the heat is sufficiently great they melt, or fuse, or liquefy. These three words—melt, fuse, liquefy—mean the same thing when used as we have just used them, viz., to turn from the solid into the liquid condition. The body, when in the liquid state, is said to be melted, fused, or liquefied. The word liquefy is sometimes used when we speak of a gas turning into a liquid, but the other two words are used with reference to solids only. Solids melt at very different temperatures or degrees of heat, platinum and carbon being two bodies which are extremely difficult to melt. When solid bodies are brought into the liquid state, either by the action of heat upon them, or by dissolving them in some liquid, the molecules are free to move about easily. And when the body is allowed to return to the solid condition, the molecules frequently unite together in a certain order, and form the regular solids which are called crystals. And since, in doing this, molecules of any other substances which may happen to be present in the liquid are more or less excluded, or left out of the crystal, crystallisation is usually performed for the sake of purifying any particular substance. There is still another property common to solids, which is very characteristic of them. A pressure put upon any portion of the surface of a solid is transmitted through the solid in one direction, and in one direction only, viz., in the direction in which the pressure is applied. That is to say, when the molecules on the surface of a solid body are pressed upon, they in their turn press upon their neighbours on the opposite side, and these again pass it on in the same direction. And in this manner the pressure is transmitted through the solid, to the side opposite to that where it was first applied. This is one of the most important characters of solids, and distinguishes them from fluids.

We may sum up briefly the principal characters of solids, which we have learned in the preceding lessons, thus :—

(1.) **A solid has a definite shape and size.**
(2.) **The force of cohesion in solids is usually strong.**
(3.) **Solids in general are difficult to compress.**
(4.) **Solids as a rule expand when heated, and melt if the heat is great enough.**
(5.) **A solid transmits pressure in one direction only.**

Any portion of matter which possesses the properties just named, we call a solid.

EXERCISES.

1. Explain the following words:—expand, fuse, cohesion, transmits.
2. Write four sentences referring to solids, each sentence containing one of the terms in the last exercise.
3. Explain clearly the difference between *melting* and *dissolving* solids. How would you proceed to melt sugar, and how would you proceed to dissolve it?
4. Give the names of six solids that will dissolve in water, six that will not dissolve in water, six metals, six fibrous solids, three transparent solids, and three solids that would melt if placed near an ordinary fire.

LESSON 8.

MEASUREMENT OF LENGTH.

It is a universal property of matter that every body, or portion of matter, must occupy some space. We cannot think of matter, without having present in our minds the idea that the matter takes up room. This property of matter is sometimes called **extension.** We express the same fact familiarly by saying that a portion of matter has a certain size. In the latter case, however, we compare the portion of matter of which we are speaking with other portions of matter, and we speak or think of its size as being large or small, in comparison with these other portions. As soon as we begin to compare things with each other as to their size, we commence to measure. In every science, measurement of some kind or other is necessary, in order that things may be exactly compared. In these lessons, the measurements we shall have to consider are those of space, of time, and of velocity. The present lesson will deal with the measurement of space, or rather with so much of it as refers to **length.** We have to consider the methods by which we ascertain and express the distance between any two points, *e.g.*, between the two ends of a rod.

We might, of course, compare the lengths of different bodies by laying them side by side. This could only be done when the bodies were present in the same place and at the same time; and at the best it would be a very inconvenient method of measurement. In all cases of measurement, it is found necessary to select some fixed **standard**, or **unit**. Of course there will be different standards adopted for the measurement of different things, and for different properties of these things; but in every case the standard used must be of the same kind as the thing to be measured. Thus the standard of length must be a certain fixed length, the standard of time a certain portion of time, and the standard of weight a certain fixed weight.

We can readily conceive what great inconvenience there would be, if each person were allowed to fix his own standard of length. In that case we should never be certain what length of cloth, for instance, we were buying, unless we measured it for ourselves. And in the same way, we could form no idea of the distance between two places from what another person told us, unless we first ascertained by what standard they measured this distance, and compared their standard with our own. Dishonest tradesmen would have great facilities for cheating their customers, and trade and commerce would necessarily suffer on that account.

From some of the old names of the measures of length, we see how people at one time tried to set about obtaining definite measures. Thus, one of their standards of length was the **cubit**, or the length of the arm from the elbow to the end of the middle finger. Another measure was the length of the **foot**, and in like manner the **nail, palm, span, fathom,** &c., were measures taken from certain parts of the human body. But since the size of these parts varies very much in different individuals, they evidently would not furnish exact standards of length.

The British imperial standard of length has been fixed by law, as the length between two marks on a certain bronze bar, which is carefully preserved in London. This standard is called the imperial **yard**, and all our other measures of space are derived from it. Thus the third part of it is called a foot, and the thirty-sixth part of it an inch, whilst 1760 lengths of the yard form a standard mile. According to some people the length of the yard was fixed as the length of the arm of King Henry the Eighth, but this is not correct, for the Saxons had a measure called the yard ; and in London there is a standard bar older than the time of Henry the Eighth, which is almost exactly the length of our present standard yard. There seems to be no doubt that the length of our yard is, as nearly as possible, the same as that of the old Saxon yard.

Several very exact copies of the present standard yard bar were ordered by Parliament to be made, and these are kept in different places, so that in case the real standard should ever be lost or injured (as once happened), one of these bars might be adopted as the standard. Other very carefully made copies are distributed to various parts of the country, in order that every person may have an opportunity of testing the accuracy of the measures he uses. A vast amount of time and trouble was spent in making this standard bar and these exact copies, since the measurement of everything else is found to depend more or less on the measurement of length, and therefore the standard of length should be as exact as we can possibly have it. The actual standard bar is made of an alloy which does not rust, and which at the same time is very strong, while every possible precaution is taken to preserve the bar from being bent, or twisted, or injured in any way. From what we learned in a previous lesson about the effects of heat on solid bodies, we know that the length of this standard yard bar will vary, to some extent, as its temperature varies. This has been taken into account, and the Act of Parliament, which orders that this bar shall be our standard of length, expressly states that the true length of the bar shall be its length, when the bar has a temperature of 62° F. (or 62 degrees on a Fahrenheit thermometer).

Our rules, and tapes, and other common instruments for measuring lengths, if properly made, represent accurately enough, for all ordinary purposes, the different divisions of the standard yard. This enables us to compare measurements with one another with great ease and certainty. An architect, for example, about to construct a building, can measure the ground and decide on the lengths of the various walls, doors, windows, &c., and mark these measurements down on his plan. The builders then construct these parts according to their own measures, and the architect may feel satisfied that there should be no difference between the lengths he has ordered and those actually made. Compasses are instruments occasionally used for setting off fixed distances, as for dividing up a line in geometry into certain portions. Callipers, again, which somewhat resemble compasses, are used for measuring the diameter of cylindrical bodies; while the openings in a wire gauge are used in a similar manner, to determine the diameters of different wires.

EXERCISES.

1. In what respects are wooden "foot-rules" superior to "tape-measures," and for what purposes are the latter more suitable than the former?
2. I have a long coil of wire, the weight of which is 1½ cwt. I have ascertained that a length of 4 feet of this wire weighs 1 oz. What is the total length of the wire?
3. A carriage-wheel has a circumference of 11 feet, how often will it revolve in the course of a journey of 5 miles?
4. The French standard of length—the metre—is equal to about 39¼ English inches, and there are 1000 metres in a kilometre. Express the distance from Liverpool to London (200 miles) in kilometres.

LESSON 9.

MEASUREMENT OF AREA AND VOLUME.

In considering the length of a line, we take no account of its breadth. Every line must have some breadth, however fine it may be drawn. Similarly we neglect the thickness of a yard measuring-rod, or the width of a two-foot rule, and have regard, in each case, to the length only.

In the present lesson, however, we shall in the first instance treat of the measurement of bodies, when we take into consideration their breadth, as well as their length. We have to consider the measurement of what is called the **area** of a surface, in other words, the extent of the surface. For this purpose, we suppose the surface of the body to be divided into a number of equal squares, and we express the area by stating the number of squares. If each side of the square measures one inch, we speak of the surface enclosed by those sides as a square inch; similarly we speak of square feet, square yards, and square miles.

Fig. 3 represents a surface which might be a piece of board, or metal, or any other substance. The long sides measure 2 inches each, and the short ones 1 inch each. We should say that such a piece was 2 inches long, and 1 inch broad. It is easily seen from the figure, that in this case the surface contains 2 square inches, as shown by the thick lines. The thin lines in the figure divide the sides into half inches; but if we suppose that each of these divisions measured one foot, we should have 4 rows of squares, each row containing 2; or altogether, the surface would contain 8 square feet. The general rule for finding the area of square and oblong surfaces is usually stated thus :—Multiply the length by the breadth, and the product will be the area. Of course it will be necessary to have the length and breadth expressed in the same units, *e.g.*, both in inches, or both in feet. It is not quite so simple to find the area of surfaces where the sides are inclined to each other, as in triangles, or where the sides are curved; still there are rules by which the area of such figures can be obtained. It is necessary to understand what is meant by area, and to know how it is measured, in order to ascertain the extent of surface of the land belonging to a farm, the extent of ponds, lakes, &c. The rules concerning the measurement of area are also applied in determining the length of carpet required to cover a room, or the cost of painting the walls of a house, at so much per square foot, &c.

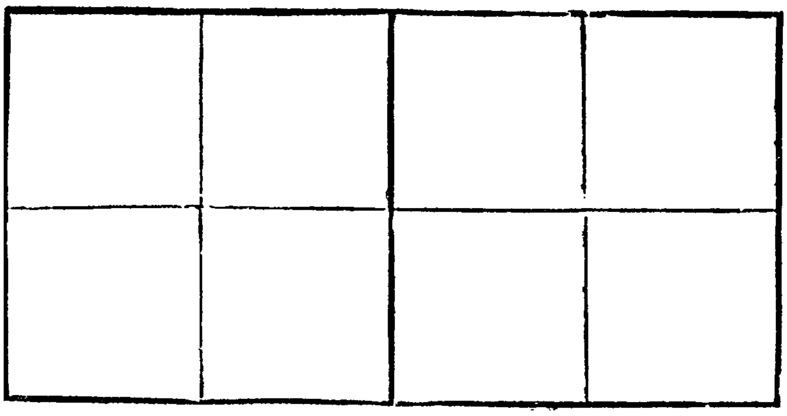

Fig. 3.

Just as in estimating the length of a body we neglect its breadth, so in estimating the surface or area of a body, we neglect its thickness. Every body must have a certain length, breadth, and thickness, though for convenience we often agree to neglect one or two of these dimensions. When we take into account the three dimensions of a body, we are said to estimate its **volume**. And to do this, we imagine the body divided into regular blocks, each face of which measures one square inch, square foot, or square yard. Such blocks are called cubes, and they are said to have a volume of one cubic inch, one cubic foot, or one cubic yard, according to the area of their faces. Let us suppose that the block represented in fig. 4 has a length of 3 inches, a breadth of 2 inches, and a height (or depth) of 2 inches. Altogether it contains 12 cubic inches, as is easily seen from the figure; and these 12 cubic inches are arranged in 3 sets, each set containing 4 of them. Thus there are 4 in the front face, the area of which is 4 square inches, (that is, 2 × 2); and three similar sets are built up one behind another, to give us the 3 inches of length of the body. The total volume is, therefore, 12 cubic inches, viz., 2 × 2 × 3. And to determine the volume of any similar body, we take the numbers expressing the length, breadth, and thickness (or depth) of the body, and multiply them together. A board measuring 20 inches long, 6 inches broad, and 2 inches thick, might be cut up into 240 (that is, 20 × 6 × 2) blocks, each block measuring one cubic inch. It is easy to determine the volume of a body, if the sides are straight and the body is of regular shape; but it becomes very difficult when the shape of the body is very irregular. We cannot enter here into the methods of ascertaining the volumes of irregular bodies; such methods will be found in books on mensuration.

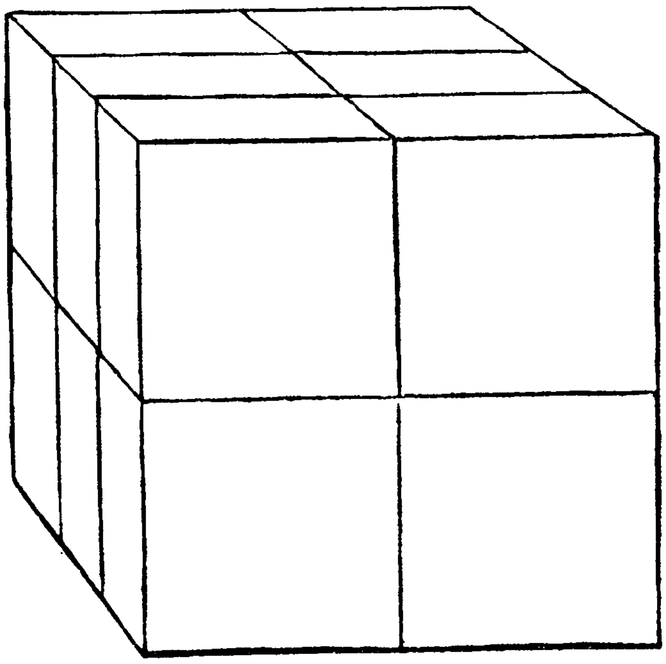

Fig. 4.

Standard **measures of capacity**, as they are termed, are used for determining the volumes of liquids, and of certain dry solids. In this country the standard measure of capacity is the imperial gallon, which is made to hold exactly ten pounds of pure water. Larger measures of capacity employed for dry solids—corn, peas, &c.—are the peck and bushel; while smaller ones, as the pint, half-pint, &c., are used for both dry solids and liquids.

We have had a great deal to say in this lesson about surfaces. There are two kinds of surfaces, termed respectively **plane** and **curved.** A plane surface is commonly spoken of as being flat or level, and is defined as being a surface which contains all straight lines drawn between pairs of points on the surface. That is to say, if we marked *any* two points on the surface, and drew a perfectly straight line, or stretched a thin string, from one point to the other, every part of the string or line would touch the surface. In mechanical operations, it is frequently of the greatest importance to be able to produce a surface, which shall be, as nearly as possible, a true plane. A perfectly plane surface has never yet been produced by any workman, and probably never will be. All the surfaces which appear so very flat and smooth to the naked eye, appear rough and irregular when seen through a microscope. Within the last few years, however, great advances have been made in the production of plane surfaces, by the use of improved tools. The ordinary carpenter's tool called a "plane," is used for the production of plane surfaces. The base of it is itself flat or plane, and in most forms of the tool this surface is considerably extended in length and breadth, so that it shall not sink or rise with every small irregularity of surface of the wood which is being planed. The edge of the cutting tool projects slightly below the "bed," or base of the plane, and by gradually shaving off the higher portions, reduces the surface of the board to an approximately true plane. By means of a "straight edge," or bar having its edge as perfectly straight as possible, laid on the board, the workman can ascertain whether any parts are above or below the general level of the surface. For if the edge of his bar be perfectly straight, and the board a true plane, then according to the definition given above, every portion of the edge should touch the board, in whatever position it might be placed. The surface of water in a vessel or a small pond might be almost considered a plane surface, but in reality it is slightly curved, as we shall see in a succeeding lesson, and corresponds with the rounded surface of the earth.

EXERCISES.

1. Which is the larger board, one having a surface of 20 square inches, or one which is 20 inches square? By how much is one larger than the other?
2. A room measures 7 yards long, by 6 yards broad. Find the cost of the carpet required, (*a*) having a width of ¾ yards, at 3s. per yard; (*b*) having a width of one yard, at 3s. 9d. per yard.
3. A cubic foot of marble weighs 178 lbs., find the weight of a solid block measuring 8 feet long, 3 feet broad, and 6 inches thick.
4. A vessel containing water measures 4 feet long, by 18 inches broad, and the depth of the water is 2 feet; a cubic foot of water weighs 62½ lbs. Find how many gallons of water the vessel contains.

LESSON 10.

LIQUIDS.

We come next to the consideration of matter in the condition of a liquid. And the first important difference we notice between liquids and solids is, that in the former the cohesion acting between the molecules is very weak, compared with the force of cohesion in solid bodies. It may be proved in many ways that liquids have some cohesion. The thin film of soapy water which forms the bag we call a soap bubble, is composed of molecules held together by the force of cohesion. If we are inclined to think that the effect is due entirely to the soap, we have only to look at a pool of water on a rainy day, or at a vessel into which a stream of water is rapidly falling, to see bubbles of water in which no soap has been dissolved. Again, if we dip a finger into water, alcohol, or most other liquids, a drop of the liquid adheres to the finger, and when we remove the finger from the liquid the drop will hang on to it for some time. Now this drop is composed of molecules, and the lowermost molecules are held to those immediately above them by the force of cohesion. Drops of dew on the leaves of plants, drops of water on dusty or greasy surfaces, and of mercury on wood or glass, all prove and illustrate the action of cohesion in liquids. Treacle and other similar liquids have so much cohesion, especially in cold weather, that a large quantity adheres to a spoon or to a glass rod thrust into them, and this falls off slowly in the form of a string. If the string of treacle dropping from a spoon be observed, it will be seen to grow gradually thinner, and at last to break. The upper portion of the string is then drawn up to the spoon, to form a more or less rounded drop on its under surface. This again is due to the action of cohesion. Treacle and glycerine have more cohesion than water, and are often spoken of as **viscous** liquids; alcohol and ether have less cohesion than water.

The cohesion in liquids is sufficient to prevent the molecules from leaving each other of themselves, but is not strong enough to retain them in fixed positions. The consequence is, that the least force is able to move the molecules of a liquid among themselves. When a liquid is put into a vessel it makes its way to the bottom, and spreads out laterally on every side so as to occupy every corner. A liquid has no definite shape of its own, but will take any shape according to the shape of the vessel containing it. The weight of the upper portions of the liquid pressing on the lower portions, causes the latter to move out in any direction in which there is a chance for them to escape; and unless the liquid be supported round the sides, it will spread out or flow. In an earlier lesson we learned that, on this account, liquids are included with gases under the term **fluids.** Liquids, like all other bodies, are acted on by the force of gravity. And because they are able to move about so freely, they always move to the lowest position they can find, and settle down so as to take a level or horizontal surface. A liquid keeps the same size, however much its shape may be changed. That is to say, a certain portion of water will have the same number of cubic inches when contained in a round bottle, as it would if held in a square vessel, however large this latter vessel might be. If liquids had no cohesion, the case would be different.

Experiments have proved that it is possible to compress liquids to a slight extent, but so difficult is it to compress them even a very little, that for a long time it was believed that they were incompressible bodies. When the force which has compressed them is removed, they come back exactly to their original size.

There is another character in which liquids differ greatly from solids, viz., the manner in which they transmit any pressure put upon them. We have already seen that a solid body transmits pressure in one direction only, but that a collection of small solids, such as sand or flour, transmits the pressure in several directions. In a liquid, where the molecules can move about far more easily than the particles of sand or flour can do, the **pressure is transmitted equally in all directions.** We know, for instance, that if a tin be filled with water, and a hole made in the side of the tin, water will flow from the hole ; and not merely trickle out, but will be forced out to some distance (fig. 5). All the water above the level of the hole, is pressing downwards on the layer of water which lies at that level. This layer not only presses downwards on the layer below, (as is shown by the water rushing out at the lower opening), but also presses out sideways, and makes its escape with some force at the opening. The force with which the jet of water rushes out diminishes as the amount of water above it becomes less, simply because the pressure of the upper water decreases. To get another instance of this general transmission of pressure by a liquid, let us take a hollow india-rubber ball and fill it with some liquid. Then laying the ball on the table, and applying pressure to it by means of the finger or a weight, we may observe that the pressure is transmitted to every part of the ball. This is proved by the fact that the liquid will escape in any direction,—upwards, downwards, or sideways,—wherever there may happen to be an opening.

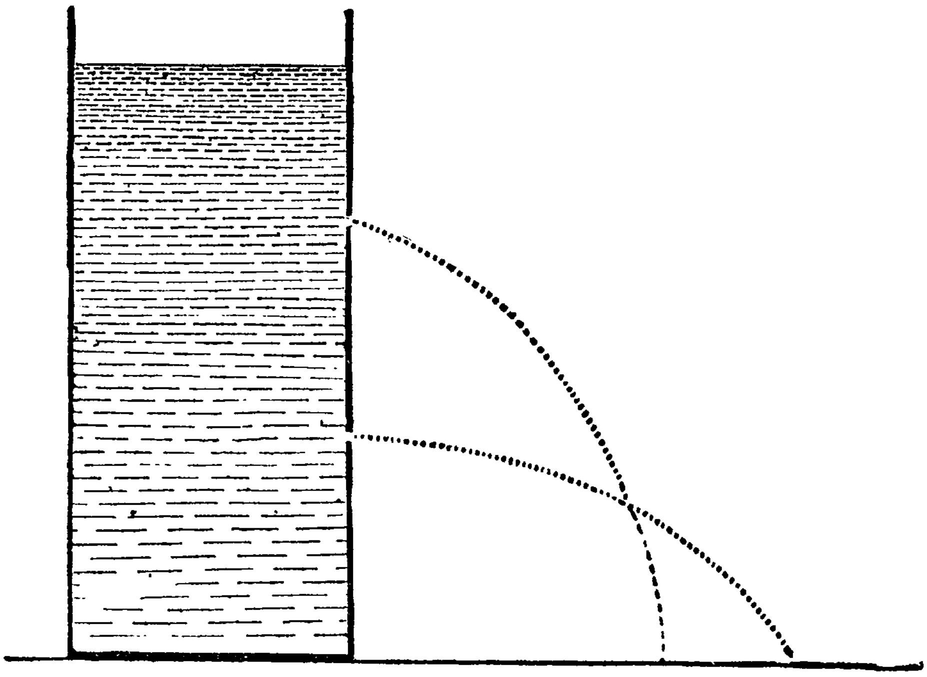

Fig. 5

EXERCISES.

1. Name ten liquids, and state which of them, if any, are viscous liquids.
2. If a bottle containing water, and another containing castor-oil, be shaken up, some bubbles of air will be entangled in the liquids, and will begin to rise to the top. In which of these two liquids will the bubbles rise the more slowly, and why?

3. If a bottle be filled with water to the top of the neck, and then a glass stopper quickly forced into the bottle, in which direction will the water in the neck move? What property of liquids does this illustrate?
4. Water is poured on the middle of a table, and runs towards one particular side; what inference can you draw from this?
5. If two drops of water are brought close together in one place, and two pieces of glass close together in another place, what difference will be observable in the two cases?
6. What property of liquids enables them to be sold by measured volume (gallon, pint, &c.) more satisfactorily than solids?
7. Explain why a piece of lead is melted when it is desired to cast it into any particular shape.

LESSON 11.

SURFACE OF LIQUIDS.

It was stated in the last lesson, that liquids in vessels arrange themselves so that their surfaces are level or horizontal. In speaking of the horizontal surface of a liquid, we mean that if we could measure the lengths of a number of lines, drawn from the centre of the earth to different parts of the surface of the liquid, these lines would all have exactly the same length. Strictly speaking, therefore, the surface of water is not flat but curved. This is very easily observed at the seaside, where we see vessels in the distance gradually sinking out of our sight—first the lower, then the upper, parts disappearing. But the surface of a plate of water, or even of a pond, is so little curved, that we may think of it for all our purposes as being plane. It is easy to understand why a liquid cannot heap itself up in one part of a vessel, when we remember that if on any side a liquid is unsupported, it will flow or spread out in that direction, and will move to as low a position as it possibly can. In small portions, however, liquids do not take level surfaces, but break up into little rounded masses, which we call drops. This may be seen when mercury is spilt on a plate, or when water is dropped on to something which it does not easily wet. The pressure of the upper portion of the drop tends to make the liquid spread out into a flat sheet; but this pressure is not so great as the cohesion, which tends to draw together the molecules of the liquid as closely as possible.

We all know that when water is poured into the body, or wide part, of a kettle or teapot, some of it passes into the spout. And we may all see, if we notice carefully, that the water rises just as high in the spout as in the body, notwithstanding the great difference in the size and shape of the two parts. What is true of the kettle, is true of all pipes or vessels which consist of two portions. When a liquid is poured into such vessels, it runs first to the lowest part of the vessel, and then rises just as high on the one side as on the other, whatever may be the shapes and sizes of the two portions. This has been known for a very long time, and people commonly express the fact by saying, that "**water finds its own level,**" though we must remember that all other liquids besides water will do just the same. Many applications are made of this principle, one of the most interesting, perhaps, being its application to the production of fountains.

Let us suppose that a tank or cistern of water is placed on the top of a building, or on a hill. If a leaden pipe were carried from the tank to the ground, and then bent up again as high as the cistern, the water would descend the pipe on one side and rise up on the other, until it reached the same height as the surface of the water in the cistern. If the pipe were cut off against the ground, as in the illustration (fig. 6), the water would issue from the pipe, with force enough to carry it nearly as high as the surface of the water in the cistern. This would constitute a fountain, and the height of the jet of water might be increased, by placing the cistern on a higher tower or hill. A more useful application of the same principle, however, is afforded by the water supply of many towns, where a reservoir placed on some neighbouring hill corresponds to the cistern in the illustration, and the pipe in the illustration represents the pipes laid along the streets. The water will be forced from any opening in these street pipes to a certain height, by the pressure of the water in the reservoir above it, and will thus be available in the case of fires, &c. The water will not rise to exactly the same height as the reservoir, since some of the force is lost in passing through the pipes, by the rubbing of the water against their sides ; and again, when it comes from the pipe, part of the force is spent in beating the air out of the way of the ascending column of water. Another interesting application is seen in the case of the water-gauge on a steam-engine, by means of which the engineman can see how high the water stands

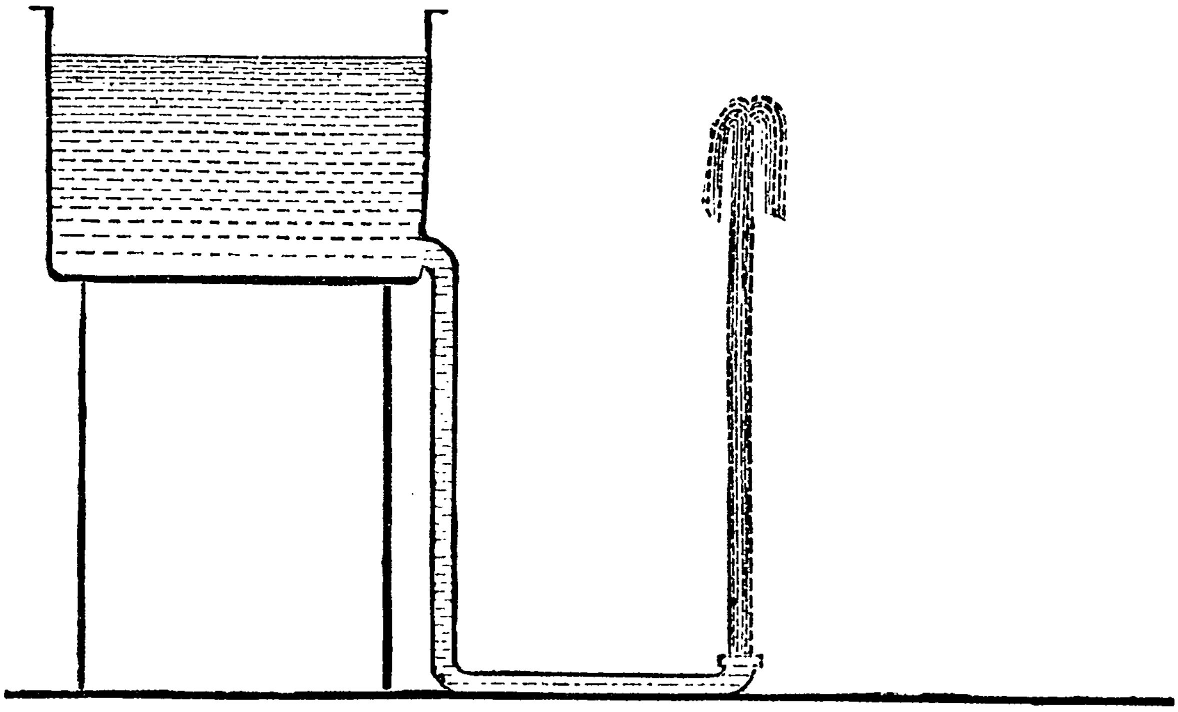

Fig. 6.

in the boiler. The gauge consists of a small tube connected with the boiler, somewhat like the spout of a kettle is connected with the body of the kettle, only that it opens into the boiler at the top as well as at the bottom.

Suppose that we wish to fasten a piece of string horizontally from one point to another, we can assure ourselves that it is horizontal in several ways. In the first place, we might get a large glass vessel of water, and ascertain whether the level of the water coincided with the level of the string. Or we might get a bent piece of glass tube containing some water, and see that the string passed exactly at the level of the water in both parts of the tube. The instrument which is most generally used to ascertain whether surfaces are horizontal is that known as the **spirit-level.** It consists of a glass tube slightly curved, as shown in fig. 7, (though not curved quite so much as there shown), nearly filled with alcohol (or spirit, as it is frequently called), leaving, however, a small bubble of air in the tube. The alcohol always lies in the lower parts of the tube, and the bubble of air in the highest part. When the two ends rest on a horizontal surface, the bubble is seen in the middle of the upper portion of the tube, but if one end be raised ever so little, the bubble moves up nearer to that end. Alcohol is used in preference to water, partly because it does not freeze even in the coldest weather, and partly because the bubble moves more freely in alcohol than in water, for a reason already given.

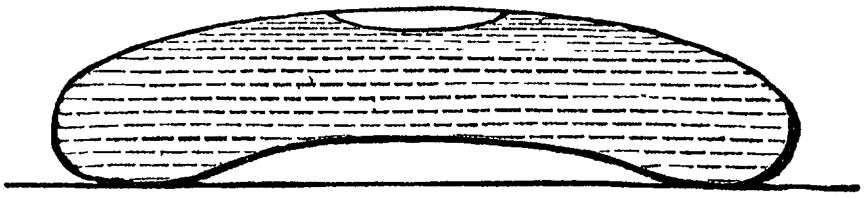

Fig. 7.

EXERCISES.

1. If an open glass tube be pushed vertically downwards into a vessel of water, how high will the water rise inside the tube?
2. Explain why the water comes from the pipes in the upper rooms of a house with less force than from those in the lower rooms.
3. Describe several methods by which you could determine a point on a rod set up in one part of a field, which should be at the same horizontal level as a point on a second rod in another part of the field not far distant.
4. If the upper portion of the spout of a kettle were cut off, to what height could the kettle be filled with water? How might such a kettle be placed so that the water could reach the lid?
5. Describe and explain the working of "lock gates" on canals.

LESSON 12.

CAPILLARY PHENOMENA OF LIQUIDS.

When a piece of loaf sugar is laid in a small quantity of water or tea, say in a teaspoon, the liquid is seen to make its way upwards to the top of the lump sugar. Similarly, when a piece of blotting paper is dipped into a drop of ink, the ink rises up into the blotting paper and remains there. The force which causes the liquid in each of these cases to make its way into and through the solid, is called **capillary force.** It is sometimes called capillary **attraction,** because in most cases there seems to be some force in the solid which attracts, or draws nearer, the liquid.

If we examine carefully the surface of the water in a glass vessel, we shall see that at the sides of the vessel the water is raised up against the glass, and stands slightly higher there than the surface of the rest of the water. This can be well seen with water in an ordinary flat-sided glass bottle, especially at the corners of the bottle. Mercury in a tumbler or bottle behaves differently ; where it comes against the glass, the edge is turned downwards, so as to stand slightly lower than the surface of the rest of the mercury. And if we try a number of liquids in succession, we shall find this rule to hold good :—Those liquids which are able to wet (that is, adhere to) the glass, such as water and alcohol, rise up against the glass : while those which do not wet the glass, such as mercury, sink down where they come in contact with it.

Again, suppose we take two pieces of sheet glass, place them nearly close together face to face, and then plunge them into water, alcohol, glycerine, turpentine, or any other liquid which wets the plates, we shall find that the liquid rises up between the plates some distance higher than the liquid in the vessel on the outside of them. And a few very simple experiments will soon show us, that the narrower the space between the plates, the higher the liquid rises ; and of course the wider the plates are apart, the less is the rise of the liquid. The same effects may be seen in glass tubes, and the same rule holds good, viz., that the smaller the diameter of the tube the greater is the rise of the liquid. In tubes, and between plates, where the space is no larger than the thickness of a hair, the effects of capillary force are very plainly seen. Such spaces are called **capillary** spaces, from a Latin word **capillaris,** meaning hair-like. If the glass plates or tubes were plunged into mercury, or if they were greased before being plunged into water, the liquid would be depressed, or forced down, against the glass ; and the narrower the space the greater would be this depression.

Now a piece of loaf sugar is simply a collection of crystals, having small spaces between them. And blotting paper is really composed of a large number of fibres matted together, having also very small spaces between the numerous fibres. When these substances are placed in water or ink, the liquid rises up the capillary spaces in them. The force, then, which causes the elevation or depression of liquids, where they come into contact with solid bodies, is called **capillary force**, and it is so called because its action is most striking in hair-like or capillary spaces.

The wicks of candles and lamps are masses of cotton fibres, which contain between the fine fibres a large number of capillary spaces. The lower portion of the wick dips into a quantity of melted tallow, or wax, or oil, or other combustible liquid, which rises up the wick by reason of the capillary force acting on it.

The roots, stems, and leaves of plants, all contain numbers of very fine tubes—vessels they are called—through which the sap rises up the plant. It is supposed that the rise of the sap in plants is due, for the most part, to the action of capillary force.

EXERCISES.

1. In a narrow glass tube the surface of water has the form of a hollow cup, while the surface of mercury is rounded like part of a ball. Explain this.
2. Why do many liquids, when kept in bottles, rise up between the neck of the bottle and the glass stopper?
3. People sometimes water plants in flower pots by letting the pot stand in a saucer of water. Describe and explain the manner in which the water gets to the roots of the plant, and even to the top of the soil.
4. Explain why ink spreads when written on paper which has not been sized or glazed, most kinds of brown paper for example, and does not so spread when written on similar paper after it has been sized.
5. Explain why a piece of dry bread will soak up a considerable quantity of water or tea.
6. When a tallow candle is put into a vessel of water, the liquid is depressed round the sides of the candle. Explain this effect.

LESSON 13.

PRESSURE OF LIQUIDS.

A liquid contained in a vessel exerts a pressure, not only on the base of the vessel, but also on its sides. And we have learned that any additional pressure which may be put on the surface of the liquid, will be transmitted by it to the base and sides of the vessel. Suppose that we have a tumbler half full of water, the water will be pressing on the base of the tumbler, and on the sides as far as it reaches. If we then pour an additional quantity of water into the tumbler, there will be an increase of pressure on the parts just named. The water last poured in will press on the water below it, and this will therefore exert a greater pressure than before on the base and sides. Those portions of the sides of the tumbler which have to support the water last added, will have to bear a less pressure than the lower portions of the sides. And if we consider the pressure on any one point of the tumbler, whether in the base or sides, it is easy to see that its amount depends on the quantity of water above it. The higher the surface of the water above the point, the greater will be its pressure. The same rule holds, not only for water, but for any liquid. Hence we may make this general statement:—**The pressure of a liquid on any part of the base or sides of a vessel containing it, varies according to the height of the surface of the liquid above that part.** A very simple experiment will prove that this rule is true for the sides of a vessel. If a tall tin be filled with water, or other liquid, and then several holes be made in the side at different distances from the top, the water will be forced out at each of these holes, as explained in lesson 10. But it will rush out with greater force, and to a greater distance, from the lowest hole than from any of the others, while, on the other hand, the highest jet will issue with the least force (fig. 5). It is plain that the pressure of the water on the sides of the vessel increases as we go deeper down below its surface.

Vessels that are to contain large quantities of liquids ought therefore to be made specially strong in their lower portions; and the deeper they are, the stronger they should be. For this reason, the walls of reservoirs, and the embankments of rivers and canals, are usually built much thicker at the bottom than at the top.

If we invert a tumbler, and push it down into a large vessel of water, only a small quantity of water enters the tumbler. The tumbler was quite full of air to commence with; if none has been allowed to escape, it follows that the air has been slightly compressed. This compression has been effected by the upward pressure of the water. It may be noticed that the deeper the tumbler is forced into the water, the greater is the quantity of liquid which enters, and the more, therefore, the air is compressed. This experiment proves in a simple manner, that **the upward pressure of a liquid varies according to the depth below the surface of the liquid.** The tumbler, in the experiment just described, may be taken to represent a **diving-bell.** In large vessels of this kind, people have gone down to considerable depths below the surface of water, air being forced down a pipe into the top of the bell, so as to keep the water from entering it at all.

Let us next suppose that we have a bent tube containing some water; we know that the water will stand at the same height in the two arms of the tube. Let us suppose that the surface of the water in each arm measures just one square inch. If we press on the surface of the water in one arm with a force of 1 lb., some of the water will be forced into the other arm, and the level of it there will be higher than before. If we wish to keep the water in both arms at the same level, a pressure of 1 lb. must be put on the water in each arm. But if, instead of the tube being of the same size throughout, one arm be wider than the other, the case will be somewhat different. Suppose that the surface of the water in one arm measures one square inch, while in the other arm it measures two square inches. Then a force of 1 lb. must be applied to each square inch of surface in the large tube, in order to balance the force of 1 lb. applied to the surface of the water in the narrower tube. That is to say, a force of 1 lb. in the narrow tube balances a force of 2 lbs. in the wider one. And if, in the latter, the surface of the water measured 10 square inches, it would require a force of 10 lbs. there to balance a force of 1 lb. in the narrow tube. This is the principle of a very important machine called the **hydrostatic press.** Sometimes this machine is spoken of as the hydraulic press, and occasionally it is called Bramah's press, after the name of the man who first made it to work successfully.

The principle of the hydrostatic press is shown in the illustration (fig. 8). It consists of a strong iron cylinder, which is connected by a side pipe with a cylinder much smaller in diameter. In each cylinder a piston presses down on the water, or oil, or other liquid, contained in it. As the liquid is forced in from the small to the large cylinder, the piston in the latter slowly rises with any weight that may be placed on it. If the area of the surface of liquid in the larger cylinder be 250 times as great as the area of the surface of the liquid in the smaller cylinder, a pressure of 40 lbs. on the small piston would balance a weight of 10,000 lbs. on the large piston. The hydrostatic press is frequently used for the lifting of very great weights, or for pressing with enormous force upon certain bodies.

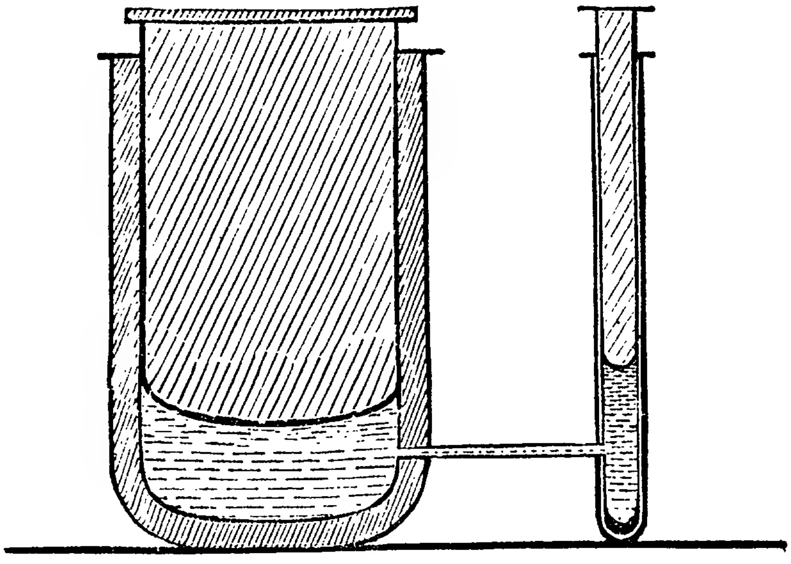

Fig. 8.

EXERCISES.

1. Empty bottles which have been carried down to great depths in the sea, have sometimes been found to have the corks which closed them forced in. Explain this.
2. If a hole be made near the bottom of the side of a vessel containing water, the distance to which the jet of water is forced gradually decreases. Explain why this is so; and state what might be done to cause the water to fall always in the same place without moving the vessel.
3. Suppose that a vessel were filled with water, and an opening made in the bottom of the vessel. If the water were allowed to run out for 10 seconds into one tumbler, for the next 10 seconds into another

tumbler, and so on, would the quantity of water collected in each of the different tumblers be the same? Give some reason for your answer.

4. If the area of the surface of liquid in the smaller cylinder of a hydrostatic press be 2 square inches, and in the larger cylinder 240 square inches, what weight on the larger piston will balance a pressure of 20 lbs. on the smaller piston?
5. A glass bottle is provided with a well-fitting cork, and is completely filled with liquid up to the cork. What would be the effect of a smart blow with a hammer on the top of the cork? Give a reason for your answer.
6. If a pail be half full of water, will the pressure on the base be altered by placing your hand in the water?

LESSON 14.

SPECIFIC GRAVITY OF LIQUIDS.

Water, mercury, or any other liquid, when poured into a bent tube, rises up into each arm, until the level of the surface of the liquid is the same in each. We may regard the liquid in such a case as a balance, or pair of scales. If we pour in liquid on one side, and still want the balance to remain as at first, we must pour in liquid to the same height on the other side. Let us suppose that we have such a bent tube, and that we pour in a quantity of mercury sufficient to fill the bend and to rise up a little in each arm, as shown in fig. 9 A. As we have seen, the level of the mercury in the two limbs will be the same; and the surface of the mercury will be rounded, as shown in the illustration, on account of the action of capillary force. Let us next pour some water into one arm of the tube, say that on the left-hand side. The pressure of the water, caused by its weight, will force down the mercury on that side, and therefore the mercury in the other arm will be raised. Suppose that we have poured in a quantity of water, just sufficient to raise the surface of the mercury in the right arm one inch above the surface of that in the left arm. Probably the first thing that we notice will be, that the column of water is much greater in height than the column of mercury which balances it. On measuring we shall find that while the column of water is about 13½ inches, the column of mercury is only 1

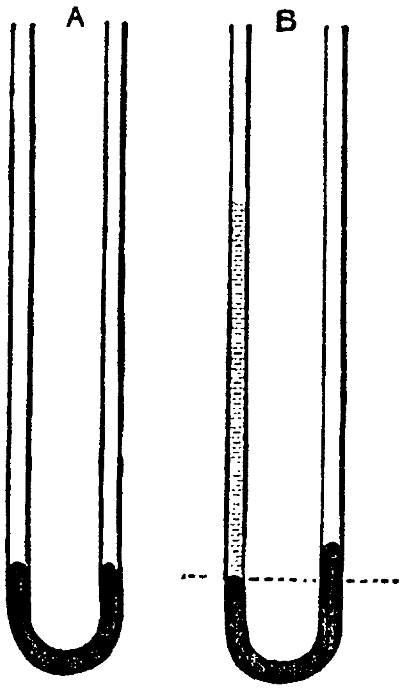

Fig. 9.

inch. We may regard the mercury below the dotted line in fig. 9 B as a balance, on one side of which we have a column of water 13½ inches high, balancing a column of mercury 1 inch high on the other side. We learn from this experiment, that if we require the same weight of water and mercury for any purpose, we must take a much greater volume of water than of mercury, in fact, 13½ times as great. On the other hand, if we take two bottles of exactly the same size, and fill one with water and the other with mercury, the mercury will weigh 13½ times as much as the water. Most people express this fact by saying that "mercury is much heavier than water;" but this is an inaccurate expression. A pailful of water would weigh more than a cupful of mercury; in that case, therefore, the water is heavier than the mercury. What people mean to say is, that a certain volume of mercury is heavier than *an equal volume* of water. We shall express the fact by saying that mercury has a greater **specific gravity** than water. By the specific gravity of a liquid, or solid, we mean **the weight of a certain volume of the body, compared with the weight of an equal volume of water.** Water is chosen, for several reasons, as the substance with which all liquids and solids shall be compared, as regards their specific gravities. The specific gravity of mercury is said to be 13½; by this is meant, that a certain volume of mercury, a gallon for example, weighs 13½ times as much as an equal volume of water. The experiment with the bent tube, which we have been considering above, has shown us one means of finding the specific gravity of mercury; there is another method which we shall consider presently.

Leaving the water and mercury in the tube, as shown in fig. 9 B, let us pour some salt water down the right arm of the tube, until the mercury in the two arms is again at the same level. Then it will be seen that the column of salt water is somewhat shorter than the column of fresh water on the other side. Here again the mercury in the tube serves as a balance, and we observe that to balance a certain quantity of fresh water, less salt water is required. We express this by saying that salt water has a greater specific gravity than fresh water. If we had made use of alcohol, or paraffin oil, instead of salt water, we should have needed a column of liquid greater than the column of fresh water on the other side. That is to say, alcohol and paraffin oil have each a less specific gravity than water.

It is very important that we should understand clearly what is meant by specific gravity. Perhaps it will help us to do so, if we consider another method of determining the specific gravity of various liquids, which is far more convenient and accurate than the one already described. A bottle is taken and its exact weight is ascertained. It is then filled in succession with different liquids, and weighed carefully each time. Subtracting the weight of the bottle itself from each result, we learn the weight of an equal volume of each of the different liquids with which we have experimented. We can then compare together the different numbers thus obtained. For example, suppose we took a bottle which would contain exactly

1 lb. of pure water, we should find that the same bottle would contain about the following weights of the different liquids mentioned :—

	lbs.		lbs.
Mercury	$13\frac{1}{2}$	or	13·5
Milk	$1\frac{1}{33}$	,,	1·03
Sea-water	$1\frac{1}{36}$	,,	1·28
Pure water	1	,,	1·00
Olive oil	$\frac{9}{10}$	,,	·9
Alcohol	$\frac{8}{10}$	,,	·8
Ether	$\frac{7}{10}$	,,	·7

The decimal numbers in the second column are those commonly made use of to express the specific gravity of those liquids.

These numbers may also be taken to express something besides the specific gravities of the different liquids; or, rather, may be taken to express what amounts to the same thing in a somewhat different manner. We like to find a reason for things as far as we can, and therefore we try to explain why a bottle full of mercury, for example, should be heavier than the same bottle full of water. If we take a box and fill it loosely with sand, the box and the sand will have a certain weight. It will be possible however to increase the weight of the box full of sand, by pressing together the loose sand already in the box and putting more in. If then we had two similar boxes filled with the same kind of sand, and one box weighed more than the other, we should conclude that in the heavier one the grains of sand were lying more closely together than in the other. The word **density** is employed to express the closeness with which the particles of a body are packed together; in other words, the more particles there are in a cubic inch of the body, the denser it is said to be. Now we can imagine that the same thing holds good of the mercury and water, as of the two boxes of sand; namely, that in the one case the particles of matter are more closely packed than in the other. Thus it is commonly said that mercury is denser than water, or that the density of mercury is 13½ times as great as that of water. The same number which expresses the specific gravity of a body serves also to express its density; for water is taken as the standard of density, as well as of specific gravity.

From the short list of numbers given above, we learn that mercury, milk, and sea-water, have each a greater density or specific gravity than water, while oil, alcohol, and ether, have each a less density or specific gravity. Mercury is the densest of all liquids; or more strictly, the densest of all bodies that we usually meet with in the liquid condition. We shall briefly consider the specific gravities of solids in the next lesson.

EXERCISES.

1. A gallon of pure water weighs 70,000 grains; find the weight of a gallon of olive oil, and of mercury, respectively.

2. If the floor of a cistern were just strong enough to support safely 6800 gallons of water, how many gallons of mercury could it support?
3. Will there be any difference between the weight of a bottle full of pure milk, and the weight of the same bottle full of milk which has been largely adulterated with water? Give a reason for your answer.
4. Describe one or more methods by which you could ascertain whether a certain liquid was pure alcohol, or a mixture of alcohol and water.
5. If the pressure of the air is sufficient to hold up a column of mercury 30 inches high in the tube of a barometer, find the height of a column of oil which the same pressure could support,
6. Describe a method by which you might ascertain whether ink or tea had the greater density.

LESSON 15.

BUOYANCY OF LIQUIDS.

We are about to consider in this lesson a most important property of liquids, and one which is of very extensive application. It will be necessary that we should consider it carefully, and try to understand it clearly, before we proceed to the subject of the next lesson. We have learned that liquids transmit pressure in all directions. A layer of liquid in the middle of a vessel is pressed on by the layers above it; and, in its turn, it presses on those below, on those above, and on the sides of the vessel where it touches them. If we plunge our hand and arm into a deep vessel of water, we feel a pressure trying to force our arm upwards out of the water. If we take a heavy stone fastened to a string, and let it dip into water, we may perceive that it feels lighter when in the water than it does when hanging in the air. These two observations would lead us to believe that when a body is immersed in water it experiences an upward pressure. If we repeated these experiments with other liquids, we should find that they all exerted a similar upward pressure on bodies placed in them, though the pressure in some cases would be greater than in others. The upward pressure which a liquid exerts on a body placed in it is termed its **buoyancy**, that is, its power to buoy up, or bear up, the body.

Suppose that we take a rather large glass marble, and, after fastening a piece of thin string to it, hang it to one arm of a balance, while in the pan on the other arm we put weights to balance the marble. This proceeding will, of course, give us the weight of the marble as it hangs in the air. If we next allow the marble, while so suspended, to hang in a tumbler nearly full of water, we may notice two things—first, that the level of the water in the tumbler rises higher than before; and secondly, that the pan containing the weights goes down, showing that it is now heavier than the other side. The explanation of the rise in the level of the water is, of course, very simple; the glass marble displaced, or pushed aside, a quantity of the water, which moved into a fresh position. It is easy to see that the quantity of water displaced by the marble would be just sufficient to make a ball of water equal in size to the ball of glass. We can express this by saying, that **the volume of liquid displaced is equal to the volume of the body immersed.**

We can imagine that the water which surrounds our glass marble presses it on every side. The pressure on the right, however, is just balanced by an equal pressure on the left, and so all round the sides. But the case is different when we consider the pressures on the top and bottom of the marble. We learned in lesson 13, that the pressure which a liquid exerts increases with the depth below the surface of the liquid. On this account, the upward pressure on the lower surface of the ball will be greater than the downward pressure on the upper surface. This will explain why the marble appears to lose weight when it dips into the water, and therefore why the opposite side of the balance on which the weights are hung goes down. The same explanation holds good in the case of the stone and of the arm previously mentioned.

Our next proceeding would be to determine, as exactly as possible, how much the marble had lost in weight; that is to say, the difference between its weight as it hangs in the water, and its weight when it is surrounded only by air. A very great number of experiments have proved that the following general rule is true: that, in every case, **the loss of weight which a body undergoes when immersed in a liquid, is equal to the weight of the liquid displaced by the body.** Thus, if we took a number of balls of the same size, but of different materials—gold, iron, marble, &c.—and immersed them in water, they would each suffer the same loss of weight, namely, the weight of a ball of water of the same size. The rule just given applies to all liquids, and not to water only. If we let our marble hang in alcohol, for example, it would lose weight equal to the weight of an equal volume of alcohol.

We may now go one step further, and suppose our glass ball immersed in several liquids in succession—alcohol, fresh water, salt water, &c. It will certainly lose weight in each case, but not the same amount. From what we learned about the specific gravities of liquids in the preceding lesson, we know that a ball of alcohol would weigh less, and a ball of salt water more, than an equal sized ball of fresh water. We should therefore expect that the upward pressure on the glass ball, which is the cause of the loss of weight, would be greatest in salt water, and least in alcohol. An experiment in each of these cases would prove that our supposition was correct. Speaking generally, we may say that **the upward pressure, or buoyancy, of any liquid depends upon its specific gravity.** The greater the specific gravity of any particular liquid, the greater will be the buoyancy of that liquid.

We have already observed that solids, like liquids, have different specific gravities. It is important that we should know a little about the specific gravity of solid bodies, and about the method by which the specific gravity of an ordinary solid body could be ascertained. The process would be very easy, if we could provide ourselves with a cubic inch of each solid. We should simply need to weigh the different blocks, and then compare the weights with the weight of a cubic inch of water, which is taken as the standard of specific gravity both for solids and liquids. Or suppose that we ascertain the number of cubic inches of water required to weigh just 1 lb., and that then we cut blocks of several different solids, each containing the same number of cubic inches. The weight of each block expressed in pounds, would give us its density or specific gravity, the density or specific gravity of water being taken as 1. The numbers we should get would be somewhat as follows :—

Water	1	Zinc	6¾
Cork	¼	Iron (cast)	7¼
Pine (white)	½	Copper	8¾
Ice	$\frac{9}{10}$	Silver	10½
Ordinary stone	2½	Lead	11¼
Glass	3	Gold	19½
Diamond	3½	Platinum	22

The method just described will serve to illustrate once more what is meant by specific gravity ; but it would be so difficult to obtain blocks of the exact size, that people would never follow out the method in practice. We must remember that to find the specific gravity of any particular solid body, all we require to know is, first, the weight of the body, and secondly, the weight of an equal volume of water. Suppose that we have a piece of stone, and wish to determine its specific gravity. We attach it to a balance and weigh it, and then let it hang in pure water while we weigh it again. It will, as we know, weigh less in the water than in the air. The loss of weight shows us precisely what would be the weight of a quantity of water of the same size as the piece of stone. This gives us all we require to know in order to determine the specific gravity of the stone. Suppose, for example, that the stone weighs 12 oz. in air and 8 oz. in water, then the weight of a quantity of water equal in size to the stone is 4 oz., *i.e.*, equal to the loss of weight. Since the stone weighs 12 oz. and a portion of water the same size only 4 oz., the specific gravity of the stone is three times as great as that of water. This is a very simple method for finding the specific gravities of most solids, but it needs to be slightly altered in the case of such substances as sugar which dissolve in water, or of bodies like wood which float on water.

EXERCISES.

1. Why is it easier to support a person in the water, than to hold up the same person on the land?
2. What two properties of a diamond distinguish it from a piece of glass?

3. If a cubic foot of water weighs 1000 oz., what will be the weight of a cubic foot of gold?
4. If a piece of silver were gilt, and then offered for sale as a piece of gold, how could the fraud be ascertained without scratching or cutting the piece?
5. A piece of gold said to be pure weighs 76 grains in air, and 70 grains in water. Is this gold pure?
6. The specific gravity of a certain kind of stone is known to be 2½; find the weight of a block of that stone measuring 8 ft. long, 3 ft. broad, and 2 ft. deep.

LESSON 16.

FLOATING BODIES.

The subject of the present lesson is very closely connected with that of our last lesson. We have to consider why it is that some solids will float on water, while others sink when placed in water, although they may float on other liquids. We shall see that it depends on the buoyancy, or, what comes to the same thing, on the specific gravity of the liquid, and on the specific gravity of the solid.

When a solid is placed in a liquid so as to be entirely covered by it, we have seen that there is an upward pressure on the solid tending to raise it. The amount of this pressure is equal to the weight of the displaced liquid. If the weight of the solid, that is, its pressure downwards, be greater than the upward pressure of the liquid, the solid will force its way down; in other words, it will sink. If the weight of the solid be less than the upward pressure of the liquid, the solid will be forced upwards, and partly out of the liquid; that is, it will float. If the two pressures be exactly equal, the solid will remain at rest in the midst of the liquid. We can express the same facts in slightly different terms, thus: **If the specific gravity of the solid be greater than that of the liquid, the solid sinks; if the specific gravity of the solid be less than that of the liquid the solid floats; if the specific gravity of the solid be equal to the specific gravity of the liquid, the solid remains at rest in any part of the liquid, so long as it is entirely covered by the liquid.** These three conditions may be easily illustrated by means of an egg, some salt, and a tumbler of water. If the egg be placed in the water it sinks to the bottom, since its specific gravity is greater than that of the water. If then some salt be dissolved in the water, the specific gravity of the liquid becomes greater than before, and its buoyancy therefore becomes greater. When the specific gravity of the liquid is equal to that of the egg, the latter will remain in any part of the liquid where it is placed. If still more salt be added to the water, its specific gravity becomes greater than that of the egg, and the egg rises to the top and floats with some portion of its bulk out of the liquid. We can explain these facts to ourselves by supposing that when the egg is put into the liquid and made to displace a portion of it, this portion of liquid endeavours to get back again into its place. There is, in consequence, a struggle between the egg and the displaced liquid, as to which shall occupy the lower position. The heavier one, that is, the one with the greater specific gravity, wins the day.

Let us consider more particularly the last case, where the egg floats in the salt water. The displaced liquid flows round and underneath the egg, and raises it up until part is uncovered. The buoyancy of the salt water can only raise the top of the egg a small distance out of the water. For the more of the egg there is uncovered the smaller is the amount of liquid displaced, and therefore the smaller will be the upward pressure. The egg rises so far only that the upward pressure of the liquid is equal to the weight of the egg. The greater the specific gravity of the liquid the greater will be its buoyancy, and the higher the egg will be raised out of the liquid. Wood or wax will float on water; iron and lead will float on mercury; and the same rules which apply to the egg in salt water, apply in these and all other similar cases. **The weight of the quantity of liquid displaced by a floating body is equal to the weight of the body.** When a solid body is placed on a liquid, it sinks until it has displaced a quantity of liquid whose weight is equal to that of the body, and then it floats in that position. But if, when the solid has sunk so low as to be just covered by the liquid, the weight of liquid displaced be not equal to the weight of the solid, the latter sinks to the bottom of the liquid.

There is a useful instrument, called the **hydrometer,** whose action depends on the principles we have just been stating. It is made somewhat in the form of a bottle, with a long neck or stem. The bottle is loaded at the bottom with mercury or shot, so as to float upright in water with about half its stem projecting above the surface. If such an instrument be placed in salt water, it floats with more of the stem uncovered than when floating in fresh water. By observing what portion of the stem is uncovered in each case, we could form some idea as to the relative quantities of salt contained in different samples of salt water. The same instrument if placed in alcohol or oil would sink deeper into those liquids, and therefore less of the stem would be uncovered. It therefore furnishes a very simple and convenient means of determining the specific gravities of various liquids, and is used in several cases to ascertain whether a certain liquid has been adulterated. For example, suppose that some alcohol were mixed with water, the specific gravity of the mixture would be less than that of water, but greater than that of pure alcohol. If we had an instrument like the hydrometer described, and having marked on the stem the point to which it would sink in water, and the point to which it would sink in alcohol, it could easily be ascertained whether the liquid were water, or pure alcohol, or a mixture of the two. And if it turned out to be a mixture of alcohol and water, we could form a pretty good idea of the relative quantities of those liquids present. Another similar instrument (called the lactometer) is frequently used to determine whether milk has been adulterated with water.

A ship floats on water for the same reason that an egg floats on strong salt water, viz., that it displaces a quantity of liquid the weight of which is exactly equal to its own weight. When the ship is loaded, it sinks lower in the water and displaces a larger volume; consequently the upward pressure of the liquid increases, and thus the extra weight is supported. The ship and the hydrometer are made hollow and broad, that they may displace far more water than they would do if the same weight of wood or glass were made into an entirely solid body. A solid piece of copper, an old penny for example, sinks in water, but the same piece of copper if beaten out into the form of a cup or boat will float. The copper boat displaces as much water as a solid piece of the same size and shape would do in the same position, but, on account of its being hollow, weighs very much less.

Different liquids in the same vessel, if they are such as will not mix with each other, arrange themselves according to their various specific gravities or densities, the densest liquid being at the bottom, and the one which has the least density at the top. Thus mercury sinks to the bottom of a vessel of water, and oil floats on the top. In some parts of the sea, near the mouth of a large river, the fresh river-water is found to float on the top of the salt sea-water for a considerable distance, on account of its smaller specific gravity.

EXERCISES.

1. An india-rubber ball filled with air floats on water; the same ball filled with water sinks. Explain this.
2. Why should a piece of wood, which at first floated easily, sink after it has been for a long time in the water?
3. A ship when loaded in a river sinks to a certain depth in the water; will there be any difference in this respect when she gets out to sea?
4. Many fishes have in their bodies a vessel resembling a bladder, which is filled with air. Of what use will such an "air-bladder" be to the fish?
5. The density of platinum is 22 times as great as the density of water. How can platinum be made to float on water?
6. For what reason does a diver hang heavy weights about him before entering the water? Will it be as difficult for him to carry the weights when in the water as when out of it?

LESSON 17.

EFFECTS OF HEAT UPON LIQUIDS.

In considering the properties of liquids, we must not forget to consider what changes they will undergo when subjected to the action of heat. We will consider a very simple experiment, which may be easily performed, and which will teach us some very important facts. Suppose we take a small glass bottle having a rather long and narrow neck, and, after filling it quite full of cold water, set it in a deep basin. On pouring hot water into the basin, we may readily notice a change taking place in the level of the water in the bottle. At first, immediately the hot water is poured into the basin, the surface of the water in the bottle would be seen to sink somewhat rapidly. Then it would begin to rise up above the neck of the bottle, and would probably overflow. We have learned that glass expands when it is heated, therefore the hot water would cause the bottle to expand and become larger. This would take place as soon as the hot water was poured in, and before the water contained in the bottle became warmed. We see at once why the level of the water in the bottle sank at first, viz., because the bottle had become larger and allowed it more room. But what about the subsequent rise of the water? When the heat had passed through the sides of the bottle and begun to warm the water in it, this water expanded, and not only overtook the bottle in its expansion but passed beyond it.

We might make similar experiments with bottles containing alcohol, oil, and other liquids; and we should soon come to the conclusion that **all liquids expand when heated.** And since the expansion of a liquid can be seen very plainly in a glass bottle, which itself expands at the same time, it is quite evident that liquids expand more than glass, when both are equally heated. If we made our experiments in bottles made of iron, we should find that the liquids expanded more than the iron. And the following general rule has been ascertained, that **a liquid expands more than a solid when both are equally heated.**

Two or three experiments, even with the common glass bottle already mentioned, would soon convince us that all liquids do not expand equally—neither at the same rate, nor to the same extent. Paraffin oil, for instance, expands quickly and to a much greater extent than water; alcohol also expands more than water, but not so quickly as the oil. Mercury expands to a less extent than water, but expands very rapidly, reaching its highest point long before the other liquids mentioned have reached theirs.

We might reason that, since liquids expand when they are heated, they would contract if cooled. To cool any body is simply to take heat away from it, and is therefore just the reverse of heating it.

Experiment would soon prove that our reasoning was correct : for on placing the bottle full of water into a basin containing still colder water, the contraction of volume would be apparent.

Let us suppose that we had a bottle with a long narrow neck, filled with one of the liquids mentioned above to a point say half-way up to the neck. We might make use of such a bottle to determine which of several liquids was the hottest. Placing it in one of the liquids, we should allow the liquid in the bottle to rise or fall, and then mark the point to which it reached when it had become steady. On placing the bottle in another of the liquids, by noticing the point of the neck to which the liquid in the bottle reached, we should be able to say whether this liquid was of the same temperature as the first, or was colder, or hotter. By temperature is meant simply the degree of heat.

There is a common instrument called the **thermometer,** which is in reality a small bottle with a long narrow neck, and is used in the manner and for the purpose just described. **The thermometer is an instrument for measuring temperature.**

Most thermometers contain mercury, but there are some which contain alcohol which is coloured red or blue so that it may be distinctly seen. Mercury is chosen for ordinary thermometers for several reasons :—(1.) It is opaque, and therefore easily seen ; (2.) it does not stick to the glass ; (3.) it expands very quickly, and very evenly ; (4.) it does not readily freeze or boil. The very fine passage down the stem of the thermometer—that is, down the neck of the bottle—is completely closed at the top. On the stem, there is marked the level at which the surface of the mercury will stand when the thermometer is placed in freezing water. This point is called the freezing point, and opposite to it, on ordinary thermometers, the number 32 is placed. Many thermometers have also marked on them the boiling point, or the level of the mercury when the thermometer is surrounded by boiling water. The number 212 is put opposite to the boiling point, and the space between freezing point and boiling point is divided into 180 equal parts called degrees.

Since a liquid expands when heated, its density must at the same time become less ; or, what comes to the same thing, it must have a less specific gravity when hot than when cold. For if we were to take a bottle full of cold water and weigh it, and then proceed to heat the bottle, some of the water would overflow. On weighing the bottle full of hot water, we should therefore find that it weighed less than when full of cold water. The same reasoning applies to all liquids and solids which expand when heated ; heat lessens the specific gravity of all such substances. When a kettle full of cold water is set over a fire, the lowermost layer of water first becomes heated, expands, and becomes less dense. It straightway rises towards the top, while colder water from above descends to take its place. This latter, in its turn, becomes heated and ascends, and thus upward and downward currents are started, which keep the water in constant circulation. A similar circulation will be set up in any other liquid if heated below. It will be readily understood that no such circulation would be produced if the liquid were heated above instead of below. It is believed that some, at any rate, of the currents in the ocean are produced in this manner, by differences in the temperature of the water at different parts.

There is still another change which heat produces in liquids, namely, it lessens their cohesion just as it does in the case of solids. This change is best seen in viscous liquids, such as treacle, glycerine, and some kinds of oil. These liquids are more or less thick at ordinary temperatures, and the colder they are made the thicker they become, and the more slowly do they move. By applying heat to them they can be made to flow quite easily. The heat appears to loosen the particles, so that they are able to change their positions more readily. Although this change is best seen in such liquids, there can be no doubt that heat produces a similar but much smaller change in all liquids.

EXERCISES.

1. Soundings have shown that there is a layer of cold water at the bottom of the ocean in many parts, and that the temperature of the water increases towards the surface. Explain these facts.
2. If an egg is carefully placed in the midst of a quantity of cold salt water of the same specific gravity as itself, explain why the egg gradually sinks when the vessel containing the water is set in a warm room.
3. Why would water be an unsuitable liquid for a thermometer?
4. To what cause would you ascribe the downward currents, which you may see when a piece of ice is floated on warm water?
5. When a thermometer is placed in a cold liquid the mercury is seen to rise up suddenly in the tube and then gradually to fall. Explain both the rise and the fall.
6. Alcohol adheres to a glass tube, but mercury does not. Explain why mercury is better than alcohol, on this account, for use in a thermometer.

LESSON 18.

CONVERSION OF LIQUIDS INTO SOLIDS AND GASES.

The action of heat produces several changes in the condition of a liquid. It causes the liquid to expand, that is, to increase in volume, and in consequence to become less dense; while if the liquid be heated from below, as liquids usually are, currents are set up in the mass of it. As another consequence of this expansion, the cohesion between the molecules of the liquid becomes less. These changes we have already considered, and we have now to consider a change quite as important, namely, the conversion of a liquid into a gas by the action of heat. Water passes into vapour or gas at all temperatures, even in winter the water in vessels gradually "dries up," or passes away in the form of vapour. There are some liquids which pass into vapour, or **evaporate** as it is termed, more easily than water. Ether and benzoline (such as is burned in small lamps), are such liquids; they evaporate very rapidly, especially when poured on the warm hand. From the surface of seas, lakes, and rivers, vapour of water is constantly passing into the air, where a great part of it collects in the form of clouds, and ultimately falls to the earth again as rain, snow, or hail.

If we place water in a vessel over a fire or any other source of heat, the vapour comes off more and more rapidly as the temperature of the water increases. And at last, if the heat be sufficient, there comes a time when the vapour is given off from the water very rapidly—so rapidly in fact, that, as it escapes through the liquid, it throws up bubbles, and keeps the surface of the liquid in a state of constant agitation. We speak of this action as the boiling of the water. The cohesion becomes less and less as the temperature increases, until at last it is insufficient to hold the molecules together, and they therefore move away from each other, and assume the state of a gas. The most curious thing, however, is this: a thermometer placed in boiling water shows us, that however great may be the heat of the fire, and however long the water may have been boiling, the temperature of the liquid remains the same as when it first began to boil.

The same facts are true of all other liquids besides water. They are probably always giving off vapour; though in the case of some liquids, such as mercury, the quantity of vapour given off is so small that it is very difficult to prove that there is any at all. When heated they give off more and more vapour as the temperature rises, until they commence to boil, when they evaporate very rapidly but do not increase in temperature. The temperature at which liquids boil is not the same for all. Under ordinary circumstances water boils at the temperature marked 212° (212 degrees) on ordinary thermometers, mercury at about 660°, while alcohol boils as soon as the temperature reaches about 173°.

Under any circumstances, when a liquid passes into the state of a gas or vapour, it must take heat from some other substance. When we pour warm water or alcohol on to our hand, as soon as the first sensation of warmth is over our hand begins to feel cold. In this case, as the liquid evaporates it abstracts from our hand the heat necessary to turn it into a vapour. Ether and benzoline evaporate much more rapidly than water, and therefore take away the heat more quickly from the hand. If we blow on to the liquid it evaporates still faster, and the surface it lies on is rendered still colder.

When a liquid is converted into a vapour or gas, the latter occupies a much larger space than the liquid did, and this is always the case. **A gas occupies a very much larger space than the liquid from which it is derived.** From the boiler of a steam-engine, which is half full of water to begin with, enough steam escapes to fill the boiler a great many times, and yet the water is not all evaporated. If a cubic inch of water could be placed in a vessel of the same size, which had walls that could be easily expanded by the steam, when all the water was converted into steam the vessel would be found to have expanded to the size of about one cubic foot. That is to say, steam occupies about 1700 times as much space as the water from which it was formed.

If a liquid is surrounded by substances colder than itself, they take heat away from it, and it gradually becomes colder than it originally was. As the liquid cools it contracts, becomes denser, has its cohesion increased, and at last, if made sufficiently cold, it **solidifies** or turns into a solid. Thus, if we take some oil, and surround the vessel containing it by ice, we can solidify or freeze the oil. A mixture of pounded ice and salt, or snow and salt, is much colder than ice alone. If we place some water in a vessel, and set the vessel in such a mixture, the water will very soon freeze. Other mixtures are known which will cool liquids still more than the mixture of ice and salt. By means of these "freezing mixtures," as they are termed, mercury has frequently been frozen and turned into a solid lump, which could be cut and hammered like a lump of lead. To prevent the solid mercury from liquefying, it has to be kept so cold that it would hurt the fingers to touch it, as much as to touch a piece of hot iron. Nearly all liquids have been solidified at various times, but alcohol is one of the few which no one has yet succeeded in converting into a solid. Hence thermometers which are to be used in cold regions, or in experiments where mercury would be frozen, contain alcohol instead of mercury. When a liquid passes *slowly* into a solid condition, the molecules frequently arrange themselves so as to build up crystals.

As a general rule, liquids shrink or contract as they solidify, and the solid therefore takes up less room than the liquid. Melted lead poured into a mould contracts in this manner, and the solid lead does not exactly fill the mould. In all such cases the solid is denser than the liquid, and while the process of melting is going on the solid lumps lie at the bottom of the liquid, which flows over and around them. This may be seen on melting wax or lead. But water and one or two more substances take up more room in the solid than in the liquid form, and consequently the solid is not so dense as the liquid. In such substances the solid floats on the liquid, as we see ice floating on water. The expansion of water on freezing is the cause of the frequent bursting of water-pipes in frosty weather.

EXERCISES.

1. **When a person has been running quickly, so that his skin is covered with perspiration, why does he feel cold on standing still?**
2. **When wet clothes are hung out to dry, what becomes of the water in them?**

3. Which liquid would produce the most severe scald, boiling water or boiling oil? Give a reason for your answer.
4. When a thaw sets in after a severe frost, people often find their water-pipes burst. Has the thaw caused them to burst? If not, why had the people not discovered the damage before?
5. Why does water, in a saucepan on the fire, get hot sooner when the lid is on the saucepan than when it is not?
6. Why does a boiler sometimes burst when a quantity of the water which it contains is suddenly converted into steam?

LESSON 19.

PROPERTIES OF LIQUIDS.

We have now been engaged for several lessons in considering the chief properties of liquids; it will be well for us in this lesson to bring together those various properties, and consider them in connection with each other. Liquids, like the other conditions of matter, consist of small particles called molecules. These molecules are held together by that force of attraction which we call cohesion. The molecules do not lie quite close to each other, for when a liquid is cooled the force of cohesion becomes stronger, and draws the molecules closer together, and we express this by saying that a liquid contracts when it is cooled. On the other hand, heat appears to force the molecules farther apart from each other, and causes the liquid to expand. The force of cohesion in liquids generally is much weaker than it is in solids; it is just strong enough, in fact, to keep the molecules together, but not sufficiently strong to fix them in one position. The consequence is, that the molecules slip and roll about among each other with the greatest ease; far more easily than the separate marbles in a bag full of marbles do, because there is not so much friction between molecules of water, for example, as between the marbles. One of the most characteristic properties of real liquids is, that **the slightest force is sufficient to move the molecules amongst each other.** In those liquids which we have called viscous liquids the cohesion is greater, and they do not yield so easily when we press on them; they are, as it were, on the way to become solids. By real liquids we mean liquids with the least possible amount of cohesion. When we remember the ease with which the molecules of a liquid move about, we can easily understand why a liquid changes its shape, according to the shape of the vessel which contains it. And further, when we recollect that all liquids have some cohesion, we can understand why it is that they do not of themselves change their size. The size of a liquid is as constant as that of a solid, and, unless we alter the temperature of the liquid, it is extremely difficult to alter its size. Liquids may be compressed, but only to a very small extent, and with great difficulty.

We have seen that liquids transmit pressure equally in all directions. When we press on any portion of a liquid, it endeavours to move away from us, and in so doing it presses on the portions of liquid below it and around it, and on whatever may be above it. So evenly is pressure distributed by a liquid, that if we press with a force of 1 lb. on a square inch of the surface of a liquid, every square inch of the surface of the vessel which the liquid touches will be pressed with an extra force of 1 lb. We say an "extra" force, because when a liquid is placed in a vessel, its weight alone causes it to press against all parts of the vessel with which it is in contact. It presses sideways on the sides of the vessel, and downwards on its base ; and we have seen that the amount of this pressure is greater the lower we go below the highest point of the liquid. The lower portions of a quantity of liquid are always pressing out laterally or sideways, because they themselves are pressed on by the portion of liquid lying above them. If we wish to keep these lower layers from moving laterally, we must support them round the sides, and thus we say that liquids need lateral support. If not supported laterally, a liquid will spread out into a sheet, or will flow, and on this account it is termed a fluid. For the same reason a liquid always takes a horizontal surface ; since, if one portion of the surface were raised higher than the rest, it would not remain so unless supported at the sides. The raised portion would settle down until the upper surface of the liquid all stood at the same level, just as the little heap of treacle does, which is formed when treacle is poured into a vessel.

Lastly, we have seen that liquids can be converted into solids on the one hand, and gases or vapours on the other—into vapours by applying heat to them, into solids by taking heat away from them. When a liquid turns into vapour it is said to evaporate ; at a particular temperature, vapour is formed very rapidly, and the liquid is then said to boil. Liquids differ very considerably in the temperatures at which they boil, and in the temperatures at which they solidify.

We may sum up the chief properties of liquids which we have considered as follows :—

(1.) **A liquid has a definite size, but an indefinite shape.**

(2.) **Liquids have little cohesion.**

(3.) **They are very difficult to compress.**

(4.) **As a rule, they expand when heated and are converted into vapours.**

(5.) **Liquids transmit pressure equally in all directions.**

(6.) **They spread out (or flow) if not supported laterally.**

EXERCISES.

1. Explain the following words:—*Evaporate*, *horizontal*, *capillary*, *thermometer*, *density*.
2. State all you can about mercury.
3. In what respects do liquids agree with solids, and in what respects do they differ from them?
4. Give the names of two liquids of greater and two of less specific gravity than water; also of two transparent and two opaque liquids.
5. I have a glass bottle containing some liquid in which a brown powder is dissolved. I constantly find a quantity of this same brown powder round the top of the neck of the bottle above the glass stopper. Explain how it gets there.
6. Explain why a solid dissolves more readily when in powder than when in a solid lump.

LESSON 20.

GASES.

We come now to consider the properties which belong to the third state or condition of matter—the gaseous state. We have learned that liquids, under the action of heat, are converted into gases. The gases thus obtained, however, only remain in the form of gases so long as they are kept above a certain temperature. If we allow them to cool down below that temperature, they pass back very readily into the liquid condition. Steam, as we know, is very easily condensed; indeed, almost as soon as it leaves the funnel of a steam-engine it is converted into a cloud consisting of numerous small drops of liquid water. The term **vapour** is commonly applied to those gases which are derived from liquids by the action of heat, and which pass back again into liquids when they are slightly cooled. All gases can be converted into liquids by suitable means; but such gases as those composing the air—oxygen and nitrogen—which are extremely difficult to liquefy, are often termed true gases. The properties we are about to consider belong to all gases, that is to say, to those which are called vapours, as well as to true gases.

In the first place, a gas has no cohesion whatever; we can separate one portion from another with the greatest ease. The molecules are very much farther removed from each other than they are in the case of either solids or liquids. This, of course, we should infer from the fact previously noticed, that a liquid always expands considerably when converted into a vapour. We have a striking proof of the great distances which separate the molecules of a gas when we endeavour to compress it. It is very easy to compress any gas; 200 cubic inches of ordinary air could, with very little trouble, be forced into the space of one cubic inch. When a gas is compressed, the molecules are, of course, much closer together than at first. And with many gases the compression can be carried on so far, that the gas turns into a liquid, that is to say, the molecules are brought so close together that cohesion again lays hold of them. But such liquids only remain as liquids under great pressure; so soon as the pressure is removed they pass again into gases. Carbonic acid gas, which is found in small quantities in the air, and which we breathe out of our bodies, can be thus liquefied by pressure. Some gases are so difficult to liquefy, that it is necessary to make them intensely cold, as well as to compress them enormously, in order to convert them into liquids. By means of combined cold and pressure, oxygen, hydrogen, and nitrogen, have recently been liquefied. Therefore we may state generally that **a gas has no cohesion: can be compressed easily, and to a great extent: and by means of cold alone, or pressure alone, or both combined, can be converted into a liquid.**

When a gas has been compressed, so soon as the pressure is removed it expands again and returns to its former size. If a quantity of gas be placed in a vessel, it expands so as to fill every portion of the vessel, no matter how small the quantity of gas may be. A gas, in fact, is always endeavouring to expand, its molecules are always striving to get farther away from each other; and they separate in all directions until they are stopped by the walls of the vessel or by some other means. Of course, as a gas expands, its density and specific gravity become less. **A gas has no definite size or shape**; its shape depends entirely on the shape of the containing vessel, and its size depends entirely on the amount of pressure put on the gas. The volume of a gas decreases as the pressure on it increases. **Gases tend to expand in all directions,** and therefore press equally on all sides of the vessel by which they are enclosed; and they must be supported on every side, otherwise they will spread out or "flow." As before stated, gases are comprised with liquids under the term **fluids.** There is another property in which they resemble liquids, and differ from solids, viz., that **they transmit pressure in all directions.** If we take a thin india-rubber ball, filled with air or gas of any kind, and press on any part of it with our finger, we shall find that the enclosed gas presses more strongly than before on every part of the ball, including the very part on which we are pressing. And the more pressure we put on the gas the greater is the amount of pressure which is transmitted to all parts of the ball.

EXERCISES.

1. Name some true gases, and also some vapours.
2. Vapour of water is produced by the flame of a paraffin oil lamp. When the glass chimney is first put on the lamp, it becomes covered with moisture, which soon passes away, while no more appears. Explain these facts as far as you can.
3. When a closed bladder half filled with gas is put under an air pump, and

the air which presses on the outside of the bladder is removed, the bladder expands. What property of gases does this illustrate?

4. In the last question, if the air be allowed to enter the air pump again, state what will take place.
5. Explain why a liquid has a greater density than a gas.
6. When a glass containing cold water is brought into a warm room, the outside is usually soon covered with moisture. Where does the moisture come from, and why should it settle on the glass?

LESSON 21.

THE AIR PUMP.

The air pump is an instrument by means of which we can withdraw the air from a vessel; or it can be slightly modified so as to enable us to force air into a vessel. As it serves to illustrate several of the properties of gases, we will, in this lesson, endeavour to understand the construction and working of a simple form of air pump. The common **syringe**, or squirt (fig. 10), contains several parts similar to those of the air pump. Thus, there is a barrel, or cylinder, which is of the same diameter in all parts except at one end, where it narrows to a small aperture. The other end of the cylinder is loosely closed by means of a cork. Through this cork passes a rod, which is attached to a kind of plate called the piston. The piston fits closely to the sides of the cylinder, being generally wrapped round with cotton or other substance, to make it fit as air tight as possible. The rod which moves the piston is called the piston rod. When the piston is moved along the cylinder towards the cork, the air in front of it is swept out around the loosely-fitting cork: while, on the other side of the piston, air will force its way in through the end aperture, to fill up the space which the piston has left. Therefore if we were to connect the opening at the end of the cylinder with the neck of a bottle, by moving the piston in the way just described, a cylinderful of air would be drawn out of the bottle. But this arrangement would not be sufficient to constitute an air pump, because, on pushing back the piston to its original position, the air which we had withdrawn would be again forced into the bottle. In the air pump, therefore, a kind of small trap-door is placed at the opening, which opens and allows air to pass into the cylinder, but closes when the air attempts to get out again. This little trap-door is called a **valve**.

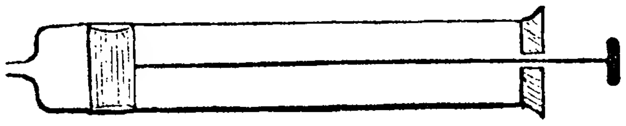
Fig. 10.

Let us now consider the air pump shown in fig. 11 A. It will be seen that there is a cylinder, piston, and piston-rod, as in the syringe. Great care is taken to make the piston fit correctly in the cylinder, and it is usually wrapped round with a collar of leather, which is kept well oiled. Two little trap-doors, or valves, are shown, one (marked v^1) opening towards the interior of the cylinder, and one (marked v^2) opening outwards. In reality the valves of the air pump are not trap-doors of the form shown in the figure. They are square pieces of oiled silk which are fastened down on two opposite sides, while the other two sides are loose. The silk covers over a small hole, and when the air presses through the hole against the silk, the latter is forced away, and the air makes its escape at the two loose sides. When the air tries to pass in the opposite direction it presses the silk closely over the opening, and thus shuts the door in its own face. If the silk is on the outside, it lets air pass out of the cylinder, but prevents it from passing in (just as v^2 does in the figure); if on the inside it allows the air to pass in (as v^1 in the figure), but prevents it from passing out. When the piston of the pump is drawn up, air passes into the cylinder through v^1, which opens for the purpose, while v^2 is closed by the pressure of the outside air. When the piston is forced down, air is pressed out of the valve v^2, while the pressure of the air in the cylinder closes the valve v^1. And this takes place every time the piston is moved up and down.

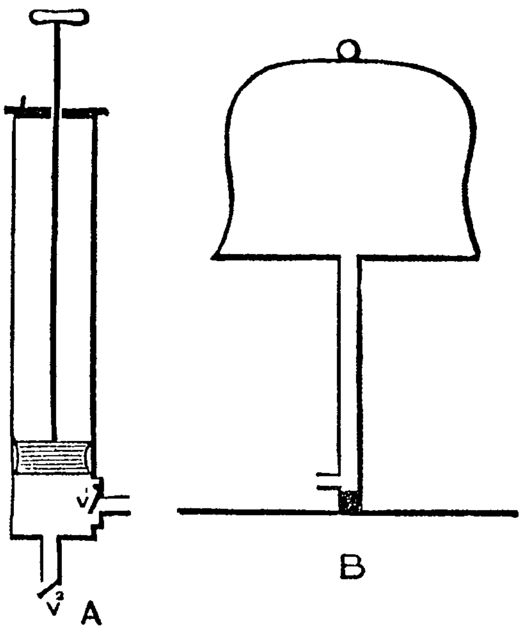

Fig. 11.

Suppose now that we have a small table (see fig. 11 B) with a pipe passing from a hole in the centre, and so arranged that we can connect this pipe with the side branch of the pump. When that is done, each time the piston is drawn up air passes through the opening in the table, and along the pipes, to get into the cylinder. And if we place a glass vessel air-tight on the table, then, by means of the pump, we can draw air out of this vessel. The vessel is called the receiver, because it receives the objects with which we wish to experiment. We can never remove the whole of the air from the receiver, but every time we raise the piston we draw out more of the air, until at last there is so little air left in the receiver, that it is not strong enough to open the valve v^1. When that is the case, there is no advantage in pumping any longer.

There are many forms of air pump; in some the cylinder is horizontal, in others it is upright or vertical, while in others again there are two cylinders to the same pump. In all the various forms, however, the principles are the same as in the one we have been describing.

EXERCISES.

1. What property of gases causes the air to enter the cylinder of an air pump when the piston is drawn away from the valve?
2. Why is it necessary that the piston of an air pump should move air-tight in the cylinder?
3. If the cylinder of an air pump is just the same size as the receiver, how much air will be left in the receiver after the first stroke of the piston? and how much after the second stroke?
4. Why is lard, or some similar substance, usually put on the bottom edge of the receiver?
5. How would you use the air pump illustrated in the lesson, to force air into a vessel?
6. If you wished to force a quantity of coal-gas into a bladder, how could you do it by means of the pump described?

LESSON 22.

PRESSURE OF THE AIR.

The atmosphere is composed of a mixture of three gases—nitrogen, oxygen, and carbonic acid. The nitrogen forms about four-fifths of the air, the oxygen about one-fifth, while the carbonic acid gas is present in very small quantity. The atmosphere also contains, mixed with these gases, more or less of the vapour of water.

We have said that one of the most characteristic properties of gases is their constant tendency to expand, and that in consequence of this tendency they exert a pressure on the surfaces of all bodies with which they are in contact. The sides of an india-rubber ball filled with air are being pressed in two opposite directions; they are being pressed outwards by the air inside the ball, and inwards by the air outside. Under ordinary circumstances, these two pressures are equal to each other, and consequently the sides of the ball are not moved one way or the other. If we place the ball under the receiver of an air pump, and remove some of the air from around it — the ball being supposed to be closed — it will expand, the sides being forced outwards by the pressure of the enclosed air. The same result might be produced by forcing more air into the ball. On the other hand, if air be withdrawn from the inside of the ball by means of the mouth or an air pump, the sides will be forced together by the pressure of the outside air.

When a receiver is placed on the plate of an air pump and some of the air withdrawn, the receiver and the plate are closely pressed together by the air outside, so that it is exceedingly difficult to separate them. As soon as the proper quantity of air is restored to the receiver it can easily be lifted, because the air on the inside then presses the receiver and the plate as strongly in one direction as the air on the outside presses them in the other. The same explanation will apply to the **sucker**, in which the receiver is represented by a piece of soft moist leather. The leather is pressed on to a flat stone, for instance, so as to force the air from between the leather and the surface, then the pressure of the air on the outer surface of the sucker holds it firmly against the stone. And since the sucker can be fixed equally well on the floor or walls of a room, or on the under surface of a table, it proves that the pressure of the air is exerted equally in all directions. **The amount of pressure of the air is very considerable, being about 15 lbs. on every square inch.** Therefore, if the sucker had a surface of 9 square inches, and all the air could be removed from underneath it, it might be made to lift a stone weighing nearly 144 lbs. As a rule, there is a considerable quantity of air left underneath the sucker, and this, of course, weakens its holding power.

If a tumbler be quite filled with water and a piece of paper laid on the top, the tumbler may be carefully inverted without any of the water running out. If the tumbler full of air be covered with paper and inverted, the paper will fall by its own weight, since the pressure of the air on the upper surface of the paper is equal to the pressure on the lower surface. But when the tumbler is filled with water, the upper pressure of the air on the lower surface of the paper is greater than the pressure on the upper surface due to the weight of the liquid. If the inverted tumbler full of water be next placed with its mouth below the surface of the water in a basin, the paper may be removed without the water in the tumbler falling down. For if the water in the tumbler were to fall down into the basin, it would have to raise the level of the water in the latter vessel. In order to do that, it would have to overcome the pressure of the air on the surface of the water, and the weight of the water in the tumbler is not sufficient for that purpose.

The pressure of the air can not only support the water in a vessel placed in the position of the tumbler just described, but it can raise the water up into the vessel under certain circumstances. If a syringe, for example, be placed with its narrow end in a vessel of water, and the piston be then drawn up, the water follows the piston into the cylinder. Similarly, if a glass tube or a straw be placed with its lower end in a liquid, and the air be withdrawn from its upper end by means of the mouth, the liquid rises up the tube. This is usually said to be due to "suction," but the sucking action of the mouth does no more than remove the air from above the liquid in the tube ; the pressure of the atmosphere outside does the rest.

A liquid will not run out of the vessel in which it is contained unless, at the same time, air can enter the vessel. In pouring a liquid quickly out of a narrow-necked bottle, the air passing into the bottle interferes with the free passage of the liquid. Beer will not run out of the tap in a barrel, unless a small hole is bored into the top of the barrel, or some other provision made, to enable the air to enter as the liquid passes out.

Otto von Guericke, the inventor of the air pump, performed a very striking experiment to illustrate the great pressure exerted by the atmosphere. He took two hollow hemispheres of copper, the edges of which fitted accurately to each other, and, having placed them together, he exhausted the air from the hollow sphere thus formed. The pressure of the external air forcing the hemispheres together was so great that it required the united strength of several horses attached to each hemisphere to tear them asunder. This experiment was performed at Magdeburg in Germany, in 1650; the apparatus for similar experiments is now always called the "Magdeburg hemispheres."

EXERCISES.

1. If you were drinking water from a tumbler by means of a straw, would it make any difference if a hole were made through the side of the straw? Give a reason for your answer.
2. Why does a sucker stick better on a flat smooth surface than on a rough one?
3. If the air, in the experiment with the Magdeburg hemispheres, has a surface of 1 square foot to act on, what force will be needed to separate the hemispheres?
4. When using an air pump similar to that shown in fig. 11, lesson 21, to pump air out of a receiver, why is it more difficult to raise the piston after several strokes than at first?
5. If a hollow india-rubber ball, having a small opening in its side, be plunged into a vessel of water, the water does not enter the ball. Explain this.
6. If the sides of the ball mentioned in exercise 5 be forced together, and then released while the ball is still in the water, describe what takes place, and explain it.

LESSON 23.

THE BAROMETER.

If a glass tube about 20 inches long, closed at one end and full of mercury, be inverted with its open end dipping below the surface of mercury in a basin, the mercury in the tube will not fall out. We have already considered a very similar experiment, namely, a tumbler filled with water and inverted into a vessel containing water. The same explanation would serve for the two cases; but, as it is very important in this lesson that we should clearly understand the reason why the mercury remains in the tube, let us go over the explanation again. We know that the whole of the mercury in the tube is pressing on the layer of mercury at the bottom, and endeavouring to force it into the basin. But if the mercury were to fall out of the tube into the basin, the surface of the mercury in the basin must necessarily be raised, and the air pressing on that surface must also be raised. In the experiment we are considering, it appears that the pressure of the mercury in the tube is not sufficient to overcome the pressure of the air.

It might be thought that the air has a great advantage over the mercury in this experiment, because it has a much larger surface to act upon. That such is not the case, however, may readily be seen, if we reason about the matter in the following way. We know that the air is pressing downwards on the surface of the mercury in the basin, and that this pressure is transmitted equally in all directions by the liquid. It is therefore transmitted to the mouth of the tube, and presses on the mercury in the tube in an upward direction. And if the mouth of the tube has an area of one square inch, the pressure transmitted to that square inch will be just equal to the pressure of the air on one square inch of the surface of the mercury in the basin. If the mouth of the tube had an area of two square inches, the pressure on that surface would be equal to the pressure of the air on two square inches, and so on. We can therefore understand that the diameter of the tube makes no difference in the result. With a narrow tube there will be only a small quantity of mercury to support, and the pressure of the air will be transmitted to a small surface only. With a wider tube there will be a greater weight of mercury to support, but the air will have all the more surface to act on. In this experiment, and those about to be described, we need only notice the height of the tube and not trouble about its diameter.

When we make use of a tube 20 inches long, and find that the mercury does not fall out, it is evident that the pressure of the air is, at least, as great as the weight of a column of mercury 20 inches high. If we make a similar experiment with a tube 33 inches in length, we shall find that all the mercury will not remain in the tube : part of it falls down into the basin, leaving at the top of the tube above the mercury an empty space called a **vacuum.** On measuring the height of the surface of the mercury in the tube above that in the basin, we shall find it to be about 30 inches ; and, however carefully and often we might repeat the experiment, we should always find this to be the case. We must try and imagine the mercury in the tube as endeavouring to force its way out, and the air outside endeavouring to force the mercury higher up the tube into the vacuum. As the mercury in the tube stands still, we conclude that the pressure of the air is not great enough to overcome that of the mercury, nor the pressure of the mercury great enough to overcome that of the air. That is to say, the pressure of the mercury in the tube is exactly equal to the pressure of the air outside. If the pressure of the air were to become greater, it would force the mercury higher up the tube, while, on the other hand, if the pressure of the air were to become less, the mercury would force its way down lower.

Suppose that we fitted up a tube such as that just described, and allowed it to stand for several days. By frequently observing the height of the column of mercury, we could ascertain whether the pressure of the air changed at all from day to day, or from hour to hour. Many such tubes are fitted up, and hung in houses and other places; they are called **barometers. A barometer is an instrument for measuring the pressure of the air.** It is found that the pressure of the air does frequently vary, that in fact the mercury sometimes rises to about 31 inches, and at other times falls as low as 28 inches. People are very interested in observing these variations in the pressure of the air, because they find from experience that, **as a rule, when the mercury rises up high in the barometer, fine weather may be expected; and when it falls down low, storms of wind or rain will very likely follow.** The barometer is therefore sometimes called a "weather glass." Some barometers are so constructed that the mercury, as it rises and falls, moves round a pointer on a dial. The words "Fair," "Rainy," &c., are printed on the dial, and it is arranged so that the pointer shall move towards "Rain" when the mercury falls, and towards "Fair" when it rises. We must remember that the barometer does not actually tell us anything about the weather; it simply shows the amount of pressure of the atmosphere, and then we have to judge from experience what kind of weather is likely to follow.

It is always desirable that we should, as far as possible, prove by actual experiments that our ideas are correct. When it was first suggested that it was the pressure of the air which supported the mercury in the tube of a barometer, it was thought necessary to ascertain in some way whether that idea was or was not correct. A very simple experiment was tried, and has since been many times repeated, as follows. The pressure of a gas, like that of a liquid, must increase as we descend deeper below the surface of the fluid. According to this rule, the pressure of the air decreases as we climb a mountain, or ascend in a balloon. And it was argued that, if it was really the pressure of the air which supported the mercury in the barometer, the height of the column ought to be less at the top than at the bottom of a mountain. A barometer was accordingly carried to the top of a mountain, and the height of the column of mercury was less there than at the bottom. Since that time, barometers have frequently been carried up mountains and taken up in balloons, and in all cases it is found that the mercury gradually falls in the barometer as the instrument is carried higher and higher. Thus, if the mercury in a barometer stood at 30 inches at the level of the sea, it would only be about 26½ inches in a barometer at the top of Mount Snowdon, and about 15 inches in one on the top of Mont Blanc. Thus it appears that on the top of the latter mountain the pressure of the air on any surface is only half as great as that at the sea-level. The barometer is frequently used to ascertain the heights of mountains; for it can be calculated how far it will be necessary to ascend, in order that the mercury may fall a certain number of inches.

When we were considering the specific gravities of liquids, we found that to balance a certain column of mercury we required a column of water 13½ times as high. Similarly, in the barometer, we have two columns of fluid balancing each other, namely, a column of mercury about 30 inches high, and a column of air reaching from the mercury in the basin to the top of the atmosphere. It is not absolutely necessary that we should use mercury as the liquid in the barometer, although it is the most convenient one. If we used water instead of mercury, we should require a column 13½ times as long as that of mercury (*i.e.*, about 33 feet of water) to balance the column of air.

Suppose that the opening of the tube of our barometer had an area of exactly one square inch. We said in the beginning of this lesson that the upward pressure on this area would be equal to the pressure of the air on one square inch of the surface of the mercury in the basin. We see, therefore, that the pressure of the air on one square inch of surface is equal to the weight of the column of mercury in such a tube. This weight is known to be about 15 lbs.; and thus we have a proof of the statement made in the last lesson, that the pressure of the air is equal to about 15 lbs. on every square inch of surface at the sea-level. In other words, the pressure of the air on the surface of the earth is equal to the pressure of an ocean of mercury covering the earth to a depth of about 30 inches.

EXERCISES.

1. What difference would it make in a barometer if a little air got into the vacuum above the mercury?
2. If we place a tube which is open at both ends upright in a vessel of mercury, and then connect the upper end of the tube with the air pump, describe and explain what will take place as we work the pump.
3. If there were two barometers, one containing mercury (specific gravity, 13½), and one containing nitric acid (specific gravity, 1½), what would be the height of the column of nitric acid, when that of the mercury was 30 inches?
4. If the pressure of the air be the same on two separate days, but the temperature on one day be higher than on the other, will there be any difference in the height of the column of mercury in the barometer on the two occasions?
5. What change in a barometer would you expect to find if you carried it carefully down into a deep mine?
6. Find the weight of a column of mercury 30 inches high, and having a section of 1 square inch; taking the weight of 1 cubic foot of water as 1000 oz., and the specific gravity of mercury 13½.
7. What advantage would there be in a barometer containing water or glycerine instead of mercury?

LESSON 24.

THE SIPHON.

The barometer is an instument whose action depends on the pressure of the air. If the air had no pressure, a column of mercury would not be supported in a tube in the manner we described in the last lesson. We are now about to consider another instrument, called the **siphon**, the action of which depends likewise on the pressure of the air. Suppose we fill with water a small glass tube which is closed at one end, and invert it carefully, so that the open end dips below the surface of the water in a basin. We know that the pressure of the air will prevent the water from falling out of the tube. By proceeding carefully, we can raise the tube out of the water in the basin without any of the water in the tube running out. The water will remain in the tube so long as we are careful to keep it exactly upright, but directly we incline it a little to one side the water runs out on the lower side, while the air enters the tube at the upper side.

As long as the tube is kept upright, the air presses upwards on the under surface of the water but cannot get in, since the water in one part will not give way more easily than in another. The reason why the air gets in when the tube is inclined we shall understand presently. Using a wider tube filled with water, it is more difficult to raise it and at the same time to keep the water in, and with a tumbler it is almost impossible to perform this experiment. The reason of this is, that there is very great difficulty in keeping the under surface of the water at the same level; for if one part of the surface be higher than another, it is easy for the air to get in. If the surface of the tumbler of water be covered with a piece of paper before it is inverted, the water may then easily be kept in. For the particles of the solid paper hold together, better than the particles of water forming the surface sheet at the mouth of the tumbler, and one part of the paper cannot fall without the rest. If we next take a glass tube, bent as in fig. 12, fill it with water, and then invert its open ends into a basin of water, we may raise it carefully out of the basin without the water running out of the tube. So soon as we incline it, however, the water runs out of the lower arm, and air rushes in at the other. Once more, if we take a similarly bent tube with unequal arms (fig. 13), and proceed in the same manner, we shall find that every time we raise it from the basin the water runs out at the longer arm. The water in the shorter arm rises up the tube and passes over to the other side, in order to fall down the longer arm, while the air rushes up the shorter tube after the water to take its place.

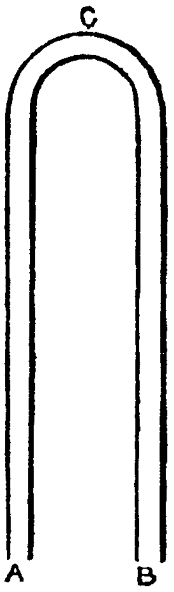

Fig. 12.

We have, so far, been describing facts which any one might easily observe on making the experiments ; let us next try to explain them. We said that the water remained in the single tube, because of the upward pressure of the air on the water at the mouth of the tube. In the same way, when we use a bent tube, we shall have the pressure of the air acting at each opening of the tube. And if the area of each opening is just one square inch, then the pressure of the air on each surface of water at the openings will be the same, and equal to about 15 lbs. In both the tubes we are considering (figs. 12, 13), the pressure of the air on the surface of water at each opening will be transmitted by the water to the top of the tube. A portion of water at C (figs. 12, 13) will thus be pressed in two opposite directions, towards the right and towards the left. What will the water at C do? The experiment shows, that in the equal-armed tube (fig. 12) it may stand still, and that in the unequal-armed tube it will move towards the longer arm. The pressure of the air transmitted by the water will not, in any case, be so strong when it reaches C as at the opening of the tube, for part of it is spent in holding up the water in the arms. In the case of the tube with equal arms (fig. 12), there is the same weight of water to hold up on each side; therefore the pressure which passes up the right arm of the tube to C will be just as great as the pressure which passes up the left arm to that point. We see why, in this case, the water in the tube does not move, simply because it is being pressed with the same force in opposite directions. With the unequal-armed tube (fig. 13) the case is different. The air has more water to support in the longer arm than in the shorter ; and, in consequence, the pressure transmitted up the longer arm to C will be less than that transmitted up the shorter arm to that point. Therefore the liquid in the tube will be forced towards the long arm, because the pressure on that side is less than on the other.

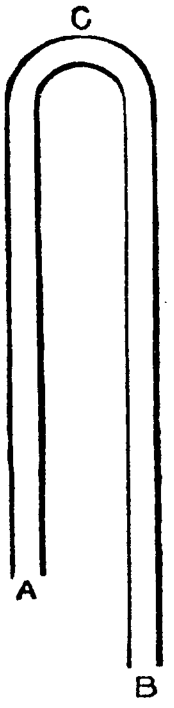

Fig. 13.

When we incline the equal-armed tube to one side, as shown in fig. 14, it comes to the same thing as making one arm longer than the other, and the water runs out on the lower side. The dotted upright lines in the figure show the difference between the two columns of water, which the air has to hold up in this case. They are drawn from the level of each opening to the level of the highest point of the tube. The explanation just given applies equally to the tube and the tumbler referred to in the first part of this lesson.

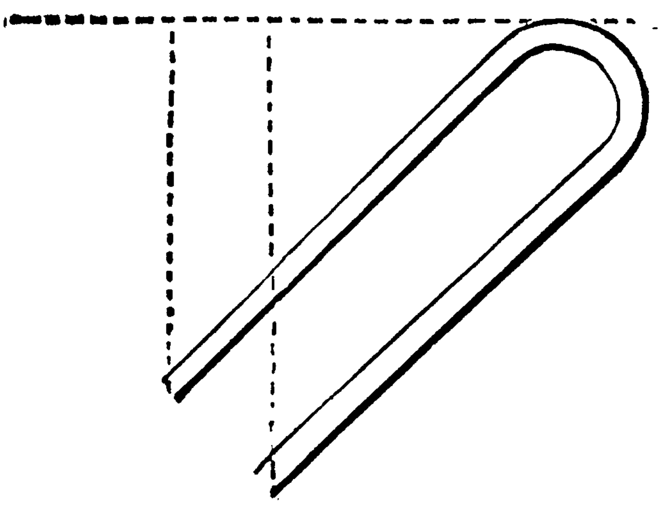
Fig. 14.

If, while the siphon is full, the shorter arm be dipped into a vessel of water, as the liquid runs out of the siphon water from the vessel will be forced up the tube by the pressure of the air. This will continue as long as the opening of the shorter arm dips below the surface of the water. The siphon can thus be employed for the purpose of transferring water, or other liquids, from one vessel to another; provided, however, that the end of the arm out of which we require the liquid to run, is lower than the surface of the liquid into which the shorter arm dips.

Since it is the pressure of the air which forces the liquid up one arm of the siphon, we can understand why, under certain circumstances, the siphon will not work. Thus, if the highest part of the siphon were more than about 33 feet above the surface of the water in the vessel, then the siphon would not act with water, although it might with a liquid of less specific gravity, such as alcohol. For a siphon to act with mercury, the air must not have to force up the mercury more than about 29 or 30 inches. And in general, the height of the siphon for use with a particular liquid, must not be greater than the height of the column of that liquid which would be required to form a barometer.

EXERCISES.

1. If two vessels containing water were set side by side, and a siphon having equal arms filled with water placed with one leg in each, would any movement of the water take place, if the level of the liquid in one vessel were higher than in the other? Give a reason for your answer.
2. In the last exercise, if any movement commenced, how long would it continue?
3. If, while a siphon were at work, a hole were made into the tube at the top, would it make any difference in the action?
4. Describe two methods by which the siphon may be filled with liquid in order to start it. Explain why it is necessary to fill the siphon with liquid at the commencement.
5. If a dry towel or handkerchief be placed in a basin of water, with one end hanging over the side, the water will drop from this end, provided it is lower than the surface of the water in the basin. Explain, as far you can, (1) why the material becomes wet at all, and (2) the continual dropping of the liquid from the end hanging outside.

LESSON 25.

PUMPS.

The familiar instrument called the syringe was described in the lesson on the air pump. It consists of a cylinder which is usually brought to a point at one end, and which contains a piston, wrapped with cotton to make it air-tight. The piston is worked by means of a piston-rod passing loosely through a cork. If the end of the cylinder be placed in water, and the piston raised, the water is forced into the cylinder by the pressure of the air acting on it. When the piston is pushed down again, the water is forced out. The syringe might be used for conveying a liquid from one vessel to another; it could be filled in one vessel, and then carried and placed in the other, before the piston was pushed down. As a rule, this would not be a very convenient process; and therefore another instrument, resembling the syringe in many respects, is used, and is termed a **pump.** By means of a pump, any liquid may be removed from one vessel to another, without the instrument itself being moved.

A pump resembles the syringe in having a cylinder, usually narrowed below, dipping into a well or vessel of water. There is also a piston, made of wood or metal, and wrapped round with a leather collar to make it fit air-tight. A piston-rod moves the piston, and is itself worked by means of a lever handle. One great difference, however, between a pump and a syringe is, that the former has in it at least two valves, while a syringe has none. The valves are for the same purpose as those in the air pump, viz., to allow of the passage of a fluid in one direction only, and to prevent it from passing in the opposite direction. In ordinary working pumps the valves are not squares of oiled silk, as in the air pump, but are more like trap-doors, made of wood or metal, and usually covered with leather. Fig. 15 illustrates a common form of valve. The principle of the construction of the common pump is shown in fig. 16. When the piston is raised, the water rises up through the narrow "suction" pipe, raises the valve at the top of that pipe, and enters the cylinder. When the piston is lowered, the water in the cylinder presses down the valve, and so shuts the door by which it could have escaped. One or two valves are placed over the holes in the piston, and as the piston passes downwards through the water, the water rises through these openings, and thus gets above the piston. When the piston is again raised these valves close, and the water above them is lifted up and passes out at the spout. This kind of pump is called the **suction and lifting pump.** The distance through which the pressure of the air has to raise the water must not be above 33 feet; and, unless the pump is exceedingly well made, and works very air-tight, the water will not be raised even to that height. There is another variety of pump frequently employed, the principle of the construction of which is shown in fig. 17. It resembles the suction and lifting pump in having at its lowest part a suction pipe, with a valve at the top of it opening towards the cylinder. It differs, however, from that pump in having no open-


Fig. 15.

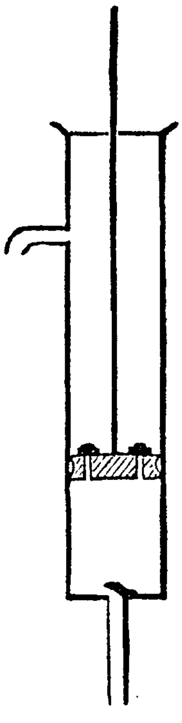
Fig. 16.

ing through the piston. The water instead of passing through and above the piston, remains constantly below it, and passes out into a pipe opening into the side of the cylinder. This pipe is guarded by a valve, which allows the water to pass into it from the cylinder, but prevents it from passing back again. When the piston is raised, the pressure of the air on the water in the well forces it up the suction pipe into the cylinder. When the piston descends, the water closes the valve at the top of the suction pipe, and passes into the side pipe. This water tries to force its way back into the cylinder when the piston is again raised, but is prevented by the valve during the working of the pump; therefore water is drawn from the well, and forced into the side pipe. This kind of pump is called the **suction and force pump.** The force pipe may be left short, and the water forced out of it to a considerable distance; or it may be prolonged, and the water carried up it to a great height. This height may be much more than 33 feet, because it is the pressure of the piston, and not of the air, which forces the water up the pipe; and in this fact consists the chief advantage of the force pump. The common fire-engine contains two force pumps combined, working alternately, first one and then the other forcing the water into a chamber, from which it is carried by the delivery pipe. The chamber contains air, and when the water is forced in by the pumps the air is compressed. We know that the more air is compressed, the greater the pressure it will exert on the walls of the chamber, and on the surface of the water. It is the pressure of the air on the water which forces the latter out of the delivery pipe. The great advantage of the air chamber is, that the water issues from the pipe in a constant steady flow, instead of in a series of jerks as it would otherwise do.

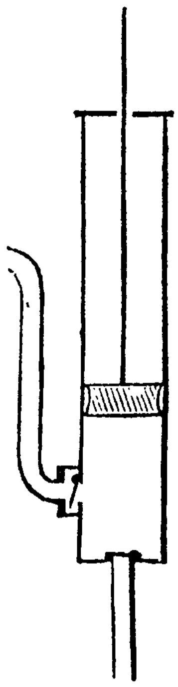

Fig. 17.

EXERCISES.

1. Draw a diagram to illustrate the construction of the fire-engine.
2. Is there any necessity for a pump to be closed at the top? Give a reason for your answer.
3. If the leather collar round the piston gets very dry and shrinks, in what way does that interfere with the working of the pump?
4. A piece of perforated iron is frequently placed at the bottom of the suction pipe of a pump, in order to keep out sand and gravel. Explain in what way those substances would injure the pump.
5. Would a suction and lifting pump work as well on the top of a mountain as at the bottom?
6. If the suction pipe cracked near the top, so that air could enter, would it make any difference in the action of the pump?

LESSON 26.

EFFECTS OF HEAT ON GASES.

Gases constantly tend to expand, and, on this account, they exert pressure on all sides of the vessels in which they are enclosed. To maintain a quantity of gas at a constant size, there must be a constant pressure on every side of it. This pressure may be exerted by the sides of a vessel, or by surrounding portions of gas. Thus, a particular portion of air in the middle of a room is prevented from expanding, by reason of the pressure of the air surrounding it. Air in contact with the floor, or walls, or ceiling of a room, is prevented from expanding in one direction by those structures, and in other directions by the air next to it. We know that if we remove part or all of this pressure, the portion of gas which we are considering will expand; that is to say, its molecules will move farther away from each other. If, on the contrary, we increase the pressure, the gas is compressed—that is, its molecules are forced nearer together. The size of a gas may therefore be changed, by altering the amount of pressure acting on it.

There is one means by which the size of a quantity of gas may be changed without altering the pressure, namely, by altering the temperature of the gas. If we heat a certain portion of air in a room, it expands; the heat forces the particles farther away from each other. Similarly, if we take an open vessel and heat the air inside it, that air expands, and part of it escapes from the vessel. A bottle full of cold air will, therefore, weigh more than the same bottle full of hot air; the difference, however, is so small that it will require a good balance, and careful weighing, to prove the fact. It follows that cold air has a greater density and specific gravity than hot air.

If we take a closed bottle full of air and heat it, it is evident that the air in this case cannot expand as it did in the open bottle. But it makes a great effort to expand, and, in consequence, exerts a greater pressure on the sides of the bottle than it did at the first. By heating the gas sufficiently, the pressure may become so great as to force the cork out of the bottle, or even to burst the sides. With hydrogen, or coal-gas, or any gas whatever in the bottle, the same results would be obtained as we have described in the case of air. We are, therefore, justified in making the following general statement:—**The effect of heat upon a gas is to increase the force with which the gas tends to expand.** Whenever a gas is heated it expands, if it can overcome the resistance of surrounding bodies.

Gases resemble liquids and solids in expanding under the action of heat; but they differ from both those forms of matter in that all gases expand equally when heated to the same extent, whereas different solids and liquids expand unequally.

When a portion of gas is cooled, the force with which it is endeavouring to expand is diminished. If we take a bottle filled with air, close it with a well-fitting cork, and then cool it, the walls of the bottle are not subjected to so great a pressure on the inside as they were at first. The pressure of the outside air will therefore tend to force in the sides of the bottle. If we leave the bottle open while we cool it, air from the outside forces its way in, since the air in the bottle has less power than before to press it outwards.

We said in an earlier part of this lesson that cold air has a greater density and specific gravity than hot air. If, then, hot and cold air are present at the same time in a room, we should expect to find the hot air in the upper, and the cold air in the lower, parts of the room. Suppose that the air in a room is all at the same temperature to commence with, and that a portion of it near the floor is then heated. The heated air, as it expands, becomes less dense, and is therefore pushed up by the colder and heavier air around. The cooler air moves to take the place of that which has ascended; and, if the heating be continued, this air in its turn ascends and is replaced by cooler air. In this manner, a circulation is set up in the gas, precisely similar to that which occurs in a liquid heated at the bottom. The moving masses of air are spoken of as **air-currents. Draughts** are air-currents on a small scale, while **winds** are nothing but large masses of air, moving sometimes with very great velocity. Winds are produced by the unequal heating of the air at different parts of the earth's surface. For example, the air at the equator is considerably hotter than at the poles, and currents of heated air ascend in the atmosphere there, and flow northwards and southwards towards the poles. The colder air from the regions to the north and south presses forwards towards the equator, to take the place of the ascending heated air. It is, in fact, the pressure of this cold air on each side, which causes the heated air to rise. On the mountain known as the Peak of Teneriffe, in the Canary Islands, about 2000 miles north of the equator, both of these winds can be perceived. At the bottom of the mountain, a cool wind is steadily blowing from the north towards the equator, while near the top of the mountain, there is a warm wind blowing steadily from the equator towards the north.

The heated air may become so much lighter than the rest of the air as to be able to carry up with it certain light solids. A paper-bag or balloon filled with hot air will ascend to some distance, on the same principle that wood ascends in water. The weight of the cool air displaced by the balloon is greater than the weight of the balloon itself and the air which it contains. The upward pressure of the surrounding air is greater than the downward pressure of the balloon. In some cases, balloons are filled with a light gas (hydrogen, or more commonly, coal-gas) instead of with hot air.

EXERCISES.

1. When an island is warmer than the water round it, in which direction will the wind near the island blow ?
2. The air which we breathe out of our mouths is warm and impure, in which part of a room will this impure air collect? Where should an opening be made to allow it to escape?
3. If a piece of smoking paper be laid on the fender in front of a fire, in which direction will the smoke pass, and why?
4. Balloons sent up filled with hot air soon descend again. Explain the cause of their descent.
5. What is the use of the holes in the brass plate just below the flame of a lamp?
6. If a bladder partly filled with air be laid in a warm place, how will it be affected?
7. Why are the hot pipes which are used to warm certain buildings always placed near the floor?

LESSON 27.

PROPERTIES OF GASES.

Matter in the state of gas is readily distinguished from matter in the solid or liquid state by several properties. The most important of these is the absence of all cohesion between the molecules ; they are free to move in any direction. And, in fact, there appears to be some repulsive force, which keeps the molecules in constant motion, endeavouring to move as far as possible away from each other. As a result of this, we find that a gas can adapt its shape to that of any vessel we may choose to put it into, and that it is also ready to take any size whatever. As we remove the pressure acting on a quantity of gas, the gas expands ; while on the other hand, as we increase the pressure the gas is compressed. These changes of volume would apparently take place to almost any extent we liked, if we could but sufficiently diminish or increase the pressure. In consequence of the property by which a gas is constantly endeavouring to expand in all directions, it exerts an equal pressure in every direction on the surfaces of the vessel which encloses it. The amount of pressure which a gas exerts increases as the gas is compressed ; in other words, the more molecules there are in contact with a given surface, the greater will be the pressure on the surface.

The air consists almost entirely of a mixture of two gases—nitrogen and oxygen—but contains also a small quantity of carbonic acid gas, more or less vapour of water, and very small quantities of other gases. Like other gases, and mixtures of gases, the air tends to expand, and consequently it exerts pressure on all surfaces with which it is in contact. The amount of this pressure does not vary to any great extent, but is usually about 15 lbs. on every square inch of surface. An instrument, termed the barometer, is employed to measure the pressure of the air, and to show the changes which take place in that pressure from day to day. Some people find it difficult to understand why the air does not move away from the earth by reason of its tendency to expand. But they forget that the force of gravity acts on the air, and holds it as much to the earth as it does a stone. Just as in the case of water, the pressure of the air increases as we go deeper and deeper down into it. We live at the bottom of the ocean of air, and, as we ascend in this ocean, the barometer shows us that the pressure becomes less.

Not only does a gas exert a pressure in all directions, on account of its constant tendency to expand, but if we apply pressure to any part of the gas, that pressure is transmitted equally in all directions. In this respect a gas agrees with a liquid.

When a gas is heated it expands, if it be free to do so. In consequence of this expansion its density becomes less, and ascending currents of heated gas are produced. Winds are strong currents of air produced in this manner, by the unequal heating of the air in different parts of the earth. For example, it has been observed that in many parts of the earth, cold currents of air are constantly passing towards the equator near the surface of the earth, while higher up in the air hot winds are blowing from the equator towards the poles. If a gas when heated cannot expand, its pressure is increased.

Some gases when cooled readily condense, or turn into liquids; such cases are termed vapours. Other gases are more difficult to liquefy, and not only require to be made very cold, but at the same time must be very much compressed.

We may sum up the chief properties of gases as follows:—

(1.) **A gas has an indefinite size, and an indefinite shape.**

(2.) **The molecules of a gas are not held together by cohesion.**

(3.) **All gases may easily be compressed.**

(4.) **They constantly tend to expand, and consequently exert pressure in all directions on surrounding bodies.**

(5.) **The tendency of a gas to expand is increased by heat.**

(6.) **Gases transmit pressure equally in all directions.**

(7.) **All gases may be liquefied by cold alone, or by cold and pressure combined.**

EXERCISES.

1. Explain the following words :—Vapour, fluid, vacuum, atmosphere.
2. Give a short account of the atmosphere.
3. In what respects do liquids and gases agree? In what respects do they differ?
4. If a bladder partly full of air were taken up in a balloon, it would be seen to expand as the balloon ascended. What is the explanation of this?
5. How would you proceed to ventilate a room?
6. Name several instruments whose action depends on the pressure of the air, and state for what purpose each is employed.

LESSON 28.

GENERAL RELATIONS BETWEEN SOLIDS, LIQUIDS, AND GASES.

We have, in the previous lessons, considered somewhat fully the chief properties which characterise matter in its three forms or states. We commenced by inquiring what was meant by matter, and arrived at the conclusion that whatever could be perceived by our senses might be called matter. And we ascertained further that matter had certain characters or properties, which we also know by means of our senses. Some of these properties belong to every kind of matter; for example, the property of weight and the property of divisibility. It is believed that matter consists of very small portions called molecules, and that these molecules are the smallest parts into which any body could possibly be divided by processes of crushing or cutting. The chemist can, however, by certain other processes, break up these molecules into still smaller portions which he calls atoms. As a rule, it is best for our purposes to consider bodies as being built up of molecules, and not to trouble about atoms until we can find time to learn something of chemistry.

There are two forces acting on the molecules of bodies, one of which tends to draw the molecules closer together, and to keep them together, while the other force tends to separate them, and to make them move away from each other. The former is said to be an attractive force, and is called cohesion; the latter is termed a repulsive force, and is known as heat. The state or condition in which we find a body at any particular time depends entirely upon the relation between these two forces. In a solid body, for instance, the force of cohesion which holds the molecules together, is so much stronger than the force of heat which tends to separate them, that they remain firmly fixed. As we increase the temperature of the body, the repulsive force of heat becomes more and more nearly equal to the attractive force of cohesion. At length the two are so nearly equal, that the cohesion is no longer able to keep the molecules fixed in one place, and they move about among each other when acted on by the slightest force. In this condition we call the substance a liquid. There is still sufficient cohesion left, however, to keep the molecules near each other. If we heat the liquid we increase the repulsive force, until at length it becomes greater than the attractive force, and then the molecules are no longer held near each other, but move away from each other as far as they are allowed to do. Matter in this latter condition is spoken of as a gas or a vapour. Many persons now believe that the molecules which compose a gas or a vapour are constantly moving about in all directions, striking against each other and against the walls of any vessel in which they may be placed. This, however, is a subject which we cannot further enter into now. We may briefly describe the different states of matter, by saying that **a solid is a portion of matter in which the attractive force between the molecules is greater than the repulsive force ; a liquid is a portion of matter in which the repulsive force is very nearly equal to the attractive force; and a gas is a portion of matter in which the repulsive force is much greater than the attractive force.**

The special properties of solids, liquids, and gases depend entirely upon the relations which we have just been considering. In consequence of the force of the cohesion in solids, for example, such bodies resist a moderate force which tends to alter either their size or their shape. For the same reason a solid body can withstand a pressure without needing to be supported laterally. On the other hand, liquids and gases yield to the slightest force, and are unable to bear the least pressure, even the pressure due to their own weight, unless they are supported round the sides. These two states of matter—liquids and gases—are comprised, as we have seen, under the term "fluids." They differ greatly in this respect, that while gases may all be very easily compressed, it is extremely difficult to compress liquids.

EXERCISES.

1. How could you prove that the air always contains some vapour of water? Where does this vapour come from?
2. The winds which come from the west, and blow over England, bring more rain than those which come from the east. Can you give any reason for this fact?
3. Why should the tops of most high mountains be covered with snow?
4. On a cold day, the breath, as it passes from our mouths, forms a little cloud of moisture; we do not see any such cloud on a warm day. Does our breath contain vapour in warm weather? How could you prove that your answer is correct?
5. How can you obtain salt from salt water?

LESSON 29.

POROSITY AND COMPRESSIBILITY.

There are many reasons for believing that the molecules of bodies are not in close contact with each other, but that small spaces are left between them, and to these spaces the name of **pores** has been given. On this account bodies are said to possess the property of **porosity,** and the bodies themselves are said to be **porous.** In ordinary language, however, those bodies only are called porous which contain spaces or pores large enough to be seen, either with the eye alone or by the aid of the microscope. Since no microscope as yet made will enable us to see the individual molecules of which bodies are composed, the spaces between the molecules are also invisible under the best microscope.

If we take a bottle and fill it loosely with sand, a very little observation will show us that the grains of sand do not lie quite close to each other, but that they are separated by spaces which we may compare to the pores separating the molecules of bodies. By means of pressure, we may force an additional quantity of sand into the bottle, or, what comes to the same thing, we can compress the sand which filled the bottle in the first case, and make it take up less room. This is done by forcing closer together the grains of sand, and at the same time decreasing the size of the spaces between them. Had the grains of sand in the first case been quite close together, we could not have compressed the mass, so that the compressibility proved the presence of spaces. By the use of a sufficient amount of pressure it is possible to compress all bodies, and therefore we conclude that all bodies contain spaces or pores. And we have learned in previous lessons that when heat is applied to a body, in almost every case it causes the body to expand, that is to say, it causes the molecules to move farther apart from each other, and therefore increases the size of the spaces between the molecules. Cold, on the other hand, causes the molecules to move nearer together, and diminishes the size of the pores. From these facts we are led to the conclusion that **in all bodies there exist minute pores or spaces between the molecules,** and we express this by saying that **porosity is a general property of matter.**

In addition to these invisible pores many bodies contain visible pores. Bread, sponge, pumice-stone, &c., contain large visible pores which can be seen without any difficulty. Our skin contains an immense number of small pores through which the sweat or perspiration comes, and these pores may be seen by means of a small magnifying glass. The existence of pores in blotting-paper and many similar substances is proved by the rise of water, ink, and other liquids in them; these pores may be readily seen by the aid of a magnifying glass. Writing-paper had large pores similar to blotting-paper when first manufactured, but these are filled up with size to prevent the ink running into them. In the same way cups and plates, and all articles made of burnt clay, are at first porous—as we may see in the case of a brick—but in vessels intended to contain liquids these pores are covered over by the "glaze" which is burnt on to them. The existence of pores in metals has been proved in several ways. One famous experiment which proved this was performed more than two hundred years ago at Florence in Italy, and is usually called the "Florentine experiment." A hollow ball of silver was filled with water and completely closed up, and then it was attempted to compress the water. The water made its way through the pores of the silver on to the outer surface. It was concluded that water was incompressible; but, as we have already seen, this conclusion was incorrect, for water and all liquids are compressible to a small extent.

That pores exist in liquids may also be proved by the fact that they are compressible, and that they contract under the action of cold. Another and very simple proof is the fact, that in a tumbler full of water a large quantity of salt or sugar may be dissolved, with little or no increase in the volume of the water. A still more satisfactory proof is afforded by mixing together water and alcohol, or water and sulphuric acid. These liquids when mixed together shrink or contract in volume; half a pint of water, for example, mixed with half a pint of alcohol gives less than a pint of the mixture. This contraction shows plainly that either one or both of the liquids contained pores.

Gases contain pores, which are believed to be very much larger than those of either solids or liquids, because of the great compressibility of gases. A portion of air, for example, may easily be compressed into $\frac{1}{50}$th or $\frac{1}{100}$th part of the space it usually occupies, and this shows us how very large the pores in ordinary air must be. And just in the same way as we see water penetrating the pores of brick or blotting-paper, so we may see one gas penetrating the pores of another. The smoke which issues from a chimney spreads out and diffuses itself into the pores of the air around.

We have said that one proof of the existence of pores in different bodies is the fact that all bodies may be more or less compressed. Some forms of matter are much more compressible than others, and this seems to be due in a great measure to the fact that they contain larger pores. As a general rule, solids and liquids are difficult to compress, and even with very great pressures their volume is but little altered. It is stated, for example, that the pressure of the atmosphere, powerful as we know it to be, is only able to compress 22,001 gallons of water into about 22,000 gallons. That is to say, if we were to take 22,000 gallons of water from the sea, and remove the pressure of the air from it, the water would expand to about 22,001 gallons only. Gases are very compressible bodies, the least increase of pressure on a gas decreases its volume. If we only double the pressure on a certain quantity of gas, it is compressed into half its original volume; while if we increase the pressure a hundred times, the volume of the gas will be only the one-hundredth part of what it was at the commencement.

When a solid bar is bent (as in fig. 18 B), it is compressed on the hollow side of the bend, and stretched or extended on the round side. This can readily be proved by measuring the length of the two sides of the bar before it is bent, and then while it is bent. It is very important for builders and other workmen to remember this condition of a bent bar, because we can readily see that the molecules on the rounded side are pulling at each other to get apart, while those on the hollow side are being forced together. If, therefore, a saw cut, or even a nail hole, be made on the round side of the bar, it is very much weakened, while such a cut would make scarcely any difference in the strength of the bar, if made on the hollow side where the molecules were being forced together.

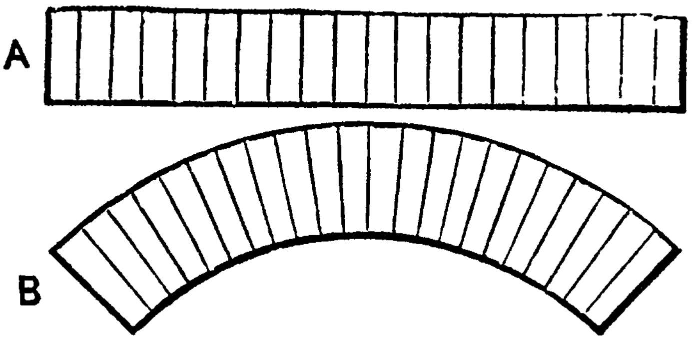

Fig 18.

EXERCISES.

1. When a piece of cork or chalk is put into water, a number of little bubbles of air escape from those bodies. Explain this.
2. Unglazed porous earthenware bottles are frequently used to keep water cool in warm weather. Explain how the water is cooled.
3. Rocks are sometimes split by driving wedges into cracks or grooves cut in the rock, and then wetting the wedges with water. Explain this fact.
4. Why is a bag of feathers so much lighter than the same bag full of flour?
5. Why does a bubble of air, when passing up the tube of a barometer through the mercury, increase its size as it ascends?

LESSON 30.

ELASTICITY.

Many bodies when they have been compressed return to their original size and shape, when the force which compressed them is removed. A ball of solid india-rubber, or a hollow india-rubber ball filled with air, are examples of such bodies. If we squeeze them in our hands so as to alter their size and shape, they spring back into their original size and shape immediately we open our hands again. The force which enables them to return to their original condition is called **elasticity**, and bodies which possess this force are called **elastic** bodies. Elasticity, however, does something more than this ; it does not begin to act when we remove our hand or whatever may be pressing on the body, but it is acting all the time while the pressure is being applied, and endeavouring to prevent any alteration taking place in the body. We may, therefore, say that **elasticity is a force which resists any change in the size or shape of a body.** If the body, after its shape or size has been altered, returns exactly to its original shape or size, it is said to be **perfectly** elastic. If its elasticity is not sufficient to bring it back exactly to its former state, it is said to be **imperfectly** elastic; while if it has no elasticity at all, it is termed an **inelastic** body. Good steel is an example of a perfectly elastic body, provided the force acting on it is not very great ; wood and copper are examples of imperfectly elastic bodies, while clay is a good example of an inelastic body. It is very probable that no bodies are quite inelastic, nor any bodies perfectly elastic, if we examine them very carefully. Practically, however, all bodies are perfectly elastic within certain limits ; that is to say, all bodies will return exactly to their original size and shape, provided the force which altered that size or shape be not too great. This is a most important point to remember. When an engineer builds an iron bridge, every train or cart which passes over the bridge bends it a little ; but the engineer makes his bridge so strong that, as soon as the train or cart has passed over, the bridge springs back into its original position. That is to say, the engineer plans his bridge so that the heaviest weight which it will have to bear will never bend it beyond the "limits of perfect elasticity." Of course if the elasticity of the bridge did not restore it to its former position, it would grow weaker and weaker each time a load passed over it.

We can test the elasticity of solid bodies in several ways ; for example, we may either stretch them, or compress them, or bend them, or twist them. Liquids and gases are very elastic bodies, but we can only test their elasticity in one way, viz., by compression. It is found that when a liquid or gas has been compressed, it returns to its original size immediately the pressure is removed ; they are, therefore, as far as we can ascertain, perfectly elastic substances.

If we take several balls, say of clay, lead, india-rubber, glass, and ivory, and let them fall on to a hard smooth surface, such as a piece of polished marble, we may notice a difference in the behaviour of the different balls. The lead and the clay would remain where they fell, and on taking them up we should find that the portion which struck the marble slab was permanently flattened. The india-rubber, glass, and ivory balls would rebound or "bounce," and on examining them we should find they were exactly round as at first. Now if we smear the surface of these three balls with oil or other substance before letting them fall, we shall see clearly by the mark they will leave on the slab that they also flattened when they fell. The difference, therefore, between the balls which rebound and those which do not is simply this, the former return to their original shape after being flattened by the fall, the latter remain flattened. In other words, india-rubber, glass, and ivory are elastic substances, while lead and clay are inelastic. It is the rounding of the elastic balls after they had been flattened which caused them to rebound. We have all seen water rebound, or splash, from the pools in the streets on a rainy day, and also from a wall or a window; this, amongst other things, proves that water is elastic. It is the elasticity of air and other gases which causes them to expand when we remove the pressure of the air from around them; for example, when we enclose gas in a partly-filled bladder and place the bladder under the receiver of an air pump. It is the elasticity of the steam which does the work in the steam-engine. All watches and many clocks are kept going by the elasticity of a steel spring, which is wound up from time to time, and which, as it unwinds, turns round the wheels of the watch or clock. The elasticity of steel is one of its most valuable properties, as it is also in the case of the substance we call india-rubber.

EXERCISES.

1. Explain the use of steel springs on carts.
2. If you stop up the hole at the end of a syringe, you are able to force down the piston to a considerable distance, but directly you remove your hand the piston is forced back again. Explain this.
3. When an india-rubber ball is thrown straight at a smooth wall or floor, in which direction does it rebound? In which direction does it rebound when thrown at the wall or floor in a slanting direction?
4. If you force a soft cork into the neck of a bottle, what causes the cork to hold itself tightly in the neck?
5. Pieces of india-rubber are often fastened to doors to shut them after they have been opened; how are they arranged? and how do they act?
6. Elastic springs are placed in the "buffers" of railway carriages; explain the use of the "buffers," and of the springs.

LESSON 31.

TENACITY, DUCTILITY, AND MALLEABILITY.

In this lesson we are about to consider some properties which belong only to solid bodies, and are found in various solids in very different degrees. One of these properties called **tenacity, is the resistance which a body offers to any force which tends to pull its particles asunder.** If we take a bar or wire of any material, iron for example, and hang a weight from the lower end of it, we can imagine that the tendency of the weight will be to pull asunder the molecules of the bar or wire. However small the weight may be, there will be some effect produced, though it may be too little for us to determine, but as we increase the weight the effect will become more and more apparent. In the first place, the wire or bar stretches more or less, and we can easily measure the amount of elongation produced by different weights. Up to a certain weight the wire or bar returns to its original size when the weight is removed, that is to say, it is perfectly elastic. But as we increase the weight we come at length to the "limits of elasticity," and if we now put on more weights we produce a permanent effect, for on removing the force we find the bar remains elongated, and has become proportionally thinner, and therefore weaker. Finally, on reaching a certain weight, the bar breaks, in other words the force applied has been sufficient to overcome the cohesion at some point in the bar. This "breaking weight," as it is called, is different of course for wires or bars of different thicknesses, and is also found by experiment to vary in bars or wires of the same thickness, but of different materials. The name **tenacity** is given to the resistance which has had to be overcome, in order to break the bar or wire in this manner. Tenacity is therefore only another name for cohesion acting in this particular direction, and whatever lessens the cohesion lessens the tenacity. If the bar or wire be heated we have already learned that its cohesion is lessened, and experiment proves that the tenacity is also less. Of all substances familiarly employed steel has the greatest tenacity, and it is stated that a wire of steel of any thickness will support about 7½ miles of similar wire without breaking. Steel wire is very much used for wire ropes in mines, bridges, &c., on account of its great tenacity. Next to steel, but very much inferior to it, comes ordinary iron ; and with less tenacity still, copper, gold, and lead come in the order named. A rod of ordinary pine wood, one inch square, cut in the direction of the fibres (or "with the grain," as a carpenter would say), will bear a weight of about four tons.

Wires are made from a piece of metal, by a process of drawing the metal through holes in plates. The wire is drawn through smaller and smaller holes until it is reduced to the thickness required. Some metals cannot be drawn into very thin wires, because they readily break, while others can be drawn out into exceedingly thin wires. **The property which enables bodies to be drawn out into wire is called ductility,** and those bodies are said to be the most ductile which can be drawn out into the thinnest wire without breaking. Gold is by far the most ductile substance known, and admits of being drawn out into threads of extreme fineness. Silver is also very ductile ; and iron, copper, and lead stand in the order named. The ease with which any particular metal may be drawn out depends upon the softness of the metal, but the extent to which it may be drawn depends altogether on the tenacity. Some substances, such as glass, are ductile only when heated.

Malleability is the property which enables a body to be

hammered or rolled out into a sheet without breaking. The ease with which a body may be beaten out depends upon its softness, but the extent depends a great deal upon the tenacity of the substance. Iron stands very low indeed in the scale of malleability, although the kind of iron termed "wrought" or "malleable" iron may be readily fashioned under the hammer into thin plates while hot. Lead is more malleable than iron, and more easily hammered out, but its tenacity is so small that the sheets begin to break before they become thin. Tin is more malleable than either iron and lead, and is rolled out into thin sheets called tin foil. Copper is also very malleable, while an alloy of copper and zinc (that is, a kind of brass), known as Dutch metal, is so malleable that it is rolled and beaten out into very thin sheets somewhat resembling gold leaf. But gold is by far the most malleable of all metals, and in fact of all substances. Gold leaf is a substance which is very well known, and is used for gilding and other purposes. The thinnest is made from very pure gold, and it is beaten out so thin that it is said more than 250,000 leaves would have to be laid on each other to make a pile one inch in height. Gold leaf is so thin as to be almost transparent; when held between the eye and the light it appears green. The gold is first rolled out into a thin ribbon between rollers, and is then cut up into pieces, which are placed between sheets of prepared calfskin (called goldbeaters' skin), and beaten with a very heavy hammer. Each sheet of gold is again cut into four and placed between fresh sheets of skin to be beaten, and this process is continued until the leaves are as thin as required.

EXERCISES.

1. Mention some purposes for which gold leaf is used.
2. What differences do you know between wrought iron and cast iron?
3. Explain why a piece of iron can be hammered out while hot and not while cold.
4. Describe one method by which you could ascertain whether brass or copper has the greater tenacity.

LESSON 32.

MEASUREMENT OF TIME.

It is extremely important that we should know something about the measurement of time. This lesson and the succeeding one will be devoted to the consideration of the methods and instruments employed for the purpose of measuring time. But first let us try to understand what is meant by time.

Two events must either happen together, or one must happen before the other. In the first case we say the events take place at the same time, in the latter case we say they occur at different times.

When one event takes place after another, we say that a certain interval or space of time has elapsed between the two events. Let us suppose that a long strip of paper was slowly and regularly moved across the table in front of us, and that the instant we heard the report of a gun we made a mark on the portion of the paper which was then before us. Let us further suppose that at the report of a second and third gun we similarly marked the paper. Then the intervals or spaces on the paper between these three marks would represent the intervals of time which elapsed between the several reports. We give this illustration to show that it is possible to measure time, just as it is possible to measure length and to measure weight. We appear to picture time to ourselves as passing on constantly and regularly like the strip of paper just described, and hence we make use of the expressions *space* of time, and *length* of time, and say that a certain time has *passed.* Again, we say that such a thing happened a *long* time ago, while it is only a *short* time since something else occurred. Expressions like these show that we compare together different intervals of time—in other words, that we measure time.

In a former lesson we observed that, in order to perform exact measurement, it was necessary to select a **standard.** And from what was there stated we know that in the present case the standard must be some portion of time, and must be as definite and as unchangeable as we can possibly get it. It seems only natural that the first standard selected should be the day and the night, and that people should speak of a certain event happening so many days and nights ago. In such case the day would be fixed as the period of light, and the night as the period of darkness. Or the day might be fixed more precisely as the interval between the rising and the setting of the sun, and the night as the interval between the setting and the rising of the sun. But it would very soon be found to be a much simpler mode of reckoning, to call the period of time which passes between one rising of the sun and the next rising a day, that is, to let the day, considered as a period of time, include a period of light and a period of darkness. We know that the rising and setting of the sun are caused by the rotation of the earth on its axis, and that the interval between one sunrise and the next is the time required for the earth to turn round once. We may say, therefore, that our standard of time is the period of rotation of the earth.

Every one knows that in spring the sun rises a little earlier each morning than it did on the previous morning, whereas in autumn the time of its rising gradually becomes later. It follows that if we measured the length of our days from sunrise to sunrise, they would be too short in spring and too long in autumn. For this reason, and for several other reasons, it has been found best to measure the length of the day from noon to noon. Of course we must have some means of ascertaining when it is exactly noon, and the astronomer tells us that noon is the instant when the sun is exactly in the south. The astronomer, by means of his telescopes and other instruments, can determine the exact moment when the sun is in the south, and by means of his observations our time, as shown by clocks and watches, is regulated. These observations are made every day when the sun can be seen at the principal observatory in England, viz., the one at Greenwich. The sun as seen from Liverpool would not appear in the south at the same time as when seen from Greenwich, and noon at Liverpool is really about twelve minutes later than noon at Greenwich. But as there are not observatories in every town to determine when it is noon there, Greenwich time is used all over England.

For convenience, we subdivide the day into hours, minutes, and seconds, and arrange instruments to mark these intervals for us. These instruments we shall consider in the next lesson.

It would obviously be as inconvenient for a person to say that he had lived 10,401 days, as to say that from Liverpool to Manchester was 54,560 yards. We need larger divisions of time than days so that we may conveniently speak of long periods of time, just as we need sovereigns and shillings so that we may conveniently carry large sums of money. The great natural divisions of time are the month and the year, the former being governed by the moon, the latter by the sun.

Every one has observed the changes which take place in the appearance of the moon, how we see it sometimes as a mere curved line or crescent of light, how this gradually increases in size until there is a complete disc which we call the full moon, and how from this full disc the size diminishes until we have once more nothing but a thin crescent of light. Ultimately this crescent disappears and the moon is entirely invisible, its dark face being turned towards us. Then the thin crescent appears again, and the changes occur in the same order as before. When the dark side of the moon is turned towards us, it is said to be the period of the new moon. From one new moon to the next new moon is about 29½ days, and as the intervals between successive new moons are very regular, and well marked, we need not be surprised to find that from very early ages time has been measured by these periods. The period of time we call a lunar month comprises only 28, instead of 29½, days; but the name **month** itself indicates a period of time measured by the moon. The division of the year into twelve unequal calendar months is in some respects inconvenient, and no one appears to be able to give any satisfactory reason why the year should be so divided.

Just as the month is regulated by the revolution of the moon round the earth, and its consequent changes of appearance to us, so the year is regulated by the revolution of the earth round the sun. We cannot go very fully here into the principle of the determination of the length of the year. It will be sufficient, perhaps, for us to say that twice in each year on all parts of the earth's surface the day and night are each 12 hours long, the sun rising at six o'clock in the morning and setting at six o'clock in the evening. One of these occasions is in the spring, about March 21st, the other is in autumn, about September 21st, and each period is called an **equinox.** The period of time between one spring equinox and the next spring equinox is called a **year.** Strictly speaking, the equinox is not a day, but a particular instant of time, which an astronomer can easily ascertain. And the interval between any two successive spring equinoxes has been found to be about 365 days 5¾ hours. Our ordinary years contain only 365 days each, so that there remains 5¾ hours over, and the equinox becomes later each year by that amount. This change would make little difference for a few years, but a little thought will show that in 100 years spring would commence on April 14th instead of March 21st, and in the course of time Christmas Day would come to be in the middle of summer. We take no account of this loss of time for three years, until we are altogether three-quarters of a day too fast, but we put ourselves right again in the fourth year by making it consist of 366 days. These long years are called **leap years,** and it is a general rule that **every year, the date of which is divisible by 4 without a remainder, is a leap year.** There is, however, still an error, for in four years we add 24 hours, which is too much. To correct this it has been decided to omit three days out of every 400 years, that is, three years which would otherwise be leap years are to have only 365 days each. Every year, the date of which is divisible by 100 but not by 400, is to consist of only 365 days. Thus, by this rule, the years 1700, 1800, and 1900 are not leap years, though divisible by 4, but 2000 A.D. will be a leap year because divisible by 400.

EXERCISES.

1. Which of the following years will be leap years :—1890, 1896, 1910, 1960, 2100, 2400?
2. If Christmas Day fall on a Monday in one year, what day of the week will it fall on in the succeeding year, (*a*) if the latter year be an ordinary year, (*b*) if it be leap year?
3. What names are given to the calendar months, and how many days are there in each?
4. What is meant by the first, second, third, and fourth quarters of the moon respectively? What is the interval between the first and second quarter?

LESSON 33.

INSTRUMENTS FOR MEASURING TIME.

We learned in the preceding lesson that time was naturally divided into days by the rotation of the earth on its axis, and into years by the revolution of the earth round the sun. A day, however, is not a sufficiently small period to enable us to measure time with accuracy.

It is necessary to agree on some mode of subdividing the day, and then to obtain instruments fitted to measure these subdivisions. The subdivisions employed are hours, minutes, and seconds; a day being divided into 24 equal parts called hours, an hour into 60 equal minutes, and a minute into 60 equal seconds.

Suppose that in the middle of a field we set up a tall stick. Whenever the sun shines on the stick a shadow will be cast on the ground, and this shadow will necessarily always be on the opposite side of the stick to that on which the sun is at the time. Thus, when the sun is in the east the shadow will point to the west, when the sun is in the south the shadow will point to the north, and so on. If now we mark a circle on the ground round the stick, the shadow will move round part of this circle, like the hand of a clock moves round the dial. If we then mark on this circle the north point, the shadow of the stick will fall on that point at noon each day. Similarly the shadow will fall on the west point at six A.M., and on the east point at six P.M. We have only to divide the spaces between W. and N., and N. and E. respectively, into six equal portions, to have a **sun-dial** (fig. 19).

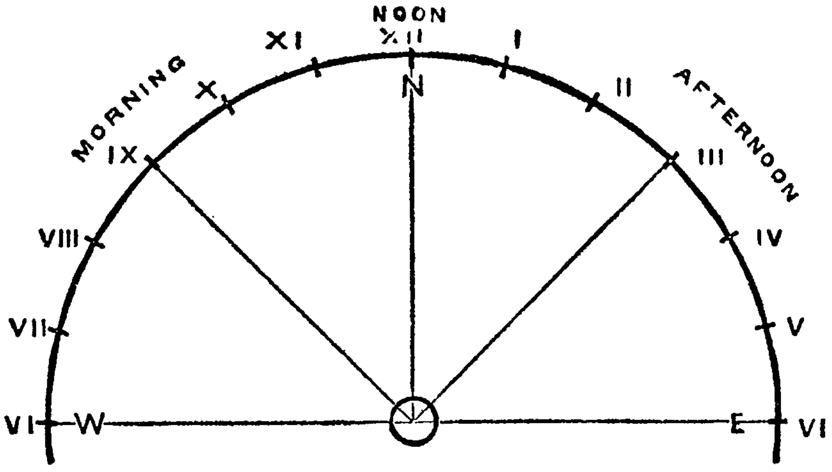

Fig. 19.

Every boy should make a small sun-dial for himself. This he can easily do with a piece of board on which to draw his circle, and an upright rod to cast a shadow. The only difficulty will be to set the board with the figure XII. pointing directly to the north, but this can easily be done if we have a clock to refer to, by arranging the board so that the shadow falls on that figure at noon.

Sun-dials are sometimes arranged to stand on the ground, or more frequently are placed on the top of a pillar, where the light of the sun will be better able to reach them. Sometimes, again, they may be seen attached to the walls of old buildings, and in these, as well as in the others, it will be noticed that the rod is not upright, but is inclined. There is a reason for this, but we cannot enter into it here. It is very evident that sun-dials are only of use when the sun is shining, and in positions where the sun can shine on them during as great a part of the day as possible. Since clocks and watches have been made to measure time so accurately, sun-dials have gradually fallen out of use. They may be seen on many old buildings, and new ones are now often set up in parks and gardens, but only as interesting ornaments. They are indeed interesting, as having been the best and almost the only means people had of measuring time until the invention of clocks and watches.

Most boys have read of the method of measuring time said to have been used by King Alfred the Great, viz., by means of burning **candles.** Candles would have one advantage over sun-dials, in that they could be used at any time either day or night. But the expense, and trouble, and uncertainty connected with them, would prevent them from ever being much employed.

Another instrument for measuring time, which most people have seen, is the **sand-glass.** This consists of two vessels connected by a narrow neck, and contains a quantity of sand, which takes up a certain time in falling through the neck from one vessel to the other. It is little used now for any purpose, except occasionally to measure the time required for boiling an egg. But formerly this instrument was very largely used, and made to measure an hour, whence it is often called the hour-glass. Although it may be made to measure a certain interval of time very accurately, still, from the fact that one instrument will measure only the interval of time for which it was constructed, and from the trouble of turning it so frequently, it has passed out of general use.

The clock (or watch, for both are constructed on the same principle) is the most perfect instrument which has yet been invented for the purpose of measuring time. Its chief advantages are: that it can be made to measure exceedingly small intervals—seconds, for example—with the greatest accuracy; that it is independent of the sun; that it will continue to work for an indefinite period without any further trouble than an occasional winding up; and that it can be made not only to measure but to record the time. To understand the principle upon which the clock works, we must in the first place direct our attention to the pendulum. If we tie an iron weight or a stone to a piece of string and hold the other end of the string in our hand, we shall have a pendulum with which we can experiment. On setting the pendulum swinging, we may observe that the time taken up by each swing of the pendulum is the same. But if we shorten the string we shall find that the pendulum will swing more quickly, that is, it will swing more times in each minute than before. A pendulum that is a little more than 39¼ inches long will swing once a second, and one about 10 inches long will swing twice in a second. The pendulum, if left to itself, gradually, but very soon, comes to rest. In order to make use of the pendulum for the purpose of measuring time, we must connect with it an arrangement which shall both keep up its motion, and also record the number of swings. The number of swings which the pendulum makes is registered in a very ingenious, though simple, manner. Connected with the upper part of the pendulum is a bar having two small arms, or projecting pieces, called "pallets" (fig. 20). These pallets are so arranged that one or other of them is always caught between the teeth of a wheel. When the pendulum swings to one side, the pallet on that side is lifted out from between the teeth, while the other pallet drops between two teeth on the opposite side. As this takes place one tooth of the wheel escapes, and for each swing of the pendulum the wheel advances one tooth. The wheel is called the "escapement wheel," and if it contained 60 teeth, it would turn round once for 60 swings of the pendulum. This wheel is so arranged that as it turns it moves other toothed wheels, and to some of these the hands of the clock are attached. The weight or spring is connected with the escapement wheel, and is always trying to turn it round. Hence every time a tooth of the wheel touches a pallet, it gives it a little push, which keeps up the motion of the pendulum. In fig. 20, the arrow shows the direction in which the escapement wheel is moved by the weight.

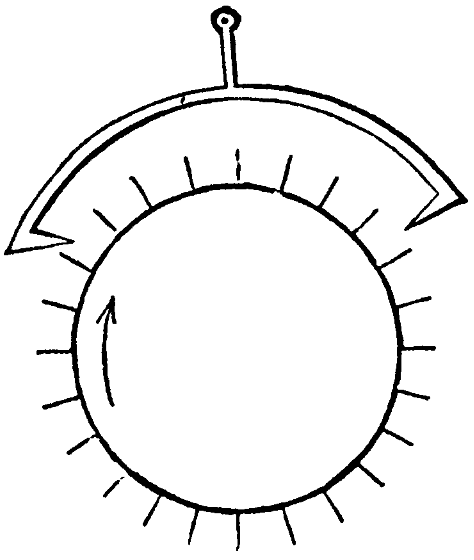
Fig. 20.

The principle of the watch is precisely the same as that of the clock, except that instead of a pendulum there is a "balance-wheel," which swings backwards and forwards.

EXERCISES.

1. A tree stands in a position where the sun can shine on it the whole day. Describe the changes in size and position which the shadow undergoes in the course of the day.
2. By what means could you ascertain which was the north, without reference to the sun?
3. Mention the chief disadvantages of candles as instruments for measuring time.
4. An ordinary clock is observed to lose time when the weather becomes warmer. Explain the cause of this.
5. Why does a clock stop when the weight is taken off, or a watch stop when the mainspring is broken?

LESSON 34.

MEASUREMENT OF VELOCITY.

Having considered in previous lessons the measurement of space and time, we are now in a position to consider the measurement of velocity. The measurement of velocity involves, as we shall see, the measurement of both time and space. Let us first understand exactly what is meant by velocity. If a body remains constantly in one position, we speak of it as being at **rest**; whereas, if it changes its position, we speak of it as in **motion**. A body in motion, therefore, moves from one position to another, that is to say, it moves over a certain space, and to do this it will necessarily require a certain time. **The rate at which a body changes its position is called its velocity,** and to measure the velocity of any body we must take into consideration both the *distance* moved over and the *time* occupied in that motion. Practically the velocity is expressed by stating the distance moved over by a body in a unit of time, and thus we speak of a velocity of 10 feet per second, meaning that the body moves at such a rate that in one second it would pass over a distance of 10 feet. Of course we need not always express the distance in feet; indeed, in many cases, it would be very inconvenient to do so. Thus, in the case of light, we say it has a velocity of nearly 190,000 miles per second. Again, we sometimes take one minute or one hour as the unit of time, and speak of an express train having a velocity of one mile per minute, or 60 miles per hour. But whatever may be the units we employ, whether feet or miles, seconds or hours, or any others, we always include two quantities in our statement of any velocity, viz., a portion of space and a portion of time.

Velocity is usually spoken of as being either **uniform** or **variable.** By *uniform* velocity we mean that an equal space is passed over by the body in each succeeding second, or any other portion of time. In other words, a body is said to have a uniform velocity when in 10 seconds it passes over ten times the space that it does in one second, in one-tenth of a second it passes over one-tenth of that space, and so on in like proportion. It follows that in the case of a body in uniform motion, if we know the distance traversed by it in one second, we can find the distance passed over by the body in any other given time by simple multiplication.

By *variable* velocity we mean velocity which changes from instant to instant, either becoming greater or less. Examples of variable velocity are seen in the case of a boy sliding: a train gradually starting or stopping: a stone thrown upwards or falling. It is plain that if we know the velocity of such a body for one second, we cannot calculate its velocity for any other time by simple multiplication. In the remainder of this lesson we shall occupy ourselves only with uniform velocity.

Now let us consider a special case in which experiments were made to ascertain the velocity of sound. For this purpose two hills were selected several miles distant from each other, and the exact distance between the hills was determined. A cannon placed on one hill was fired, while persons on the opposite hill observed the time which passed between their seeing the flash and hearing the noise of the discharge. In this way they ascertained the time required for sound to travel over the distance between the two hills. And as we may consider that sound travels with a uniform velocity, it was easy for these experimenters to calculate how far sound travelled in one second. Thus, suppose the distance between the hills was 9 miles, or 47,520 feet, and that the time occupied by the sound in its journey from one hill to the other was about 42½ seconds, then a simple calculation shows us that in one second the sound had travelled 1120 feet. The velocity of sound is therefore said to be 1120 feet per second. Remembering this number we are able, during a thunderstorm, to find out the distance at which any flash of lightning occurs. The sound of the thunder and the light of the flash start at the same time; but while the light reaches us instantly, the sound travels with a velocity of only 1120 feet per second. If we then count the number of seconds which pass between our seeing the lightning and hearing the thunder, and multiply that number by 1120, the answer will give the distance from us in feet at which the lightning discharge occurred.

We will now consider another example of finding the velocity of a body—viz., the velocity of a cannon ball, or shot, immediately after leaving the cannon. Here, again, arrangements are made to measure a distance, and a period of time. A wire screen is set up near the mouth of the cannon, and a second similar screen is set up at a distance of a hundred feet from the first, both being so placed that the shot must tear its way through them in succession. By the aid of electricity the time at which the shot tears through each screen can be accurately noted, and therefore the interval of time between its breaking through the two screens is known. Suppose, for example, that it is found in a particular case that this interval is one-tenth of a second, the velocity of the shot would be expressed as 1000 feet per second, or nearly 700 miles per hour.

What is meant by this last statement that the velocity of the shot would be about 700 miles per hour? It is very certain that the cannon ball would not travel 700 miles, neither would it be moving for an hour. The statement means, however, that were the ball to continue moving for an hour with the same velocity that it had between the screens, it would then travel 700 miles. In the same way, a man may have only half a mile to walk, and yet we may say of him that he walks at the rate of four miles an hour; meaning that were he to walk at the same rate for the space of an hour he would traverse a distance of four miles.

EXERCISES.

1. Light moves with a velocity of 186,000 miles per second; how long will it require to pass to the earth from the sun, when the latter is at a distance of ninety-three millions of miles from the earth?

2. How far are you from a ship at sea, when you can count seven seconds between the time of seeing the flash and hearing the report from a gun fired on the vessel?

3. How would you express the velocity of a carrier pigeon which could fly from Liverpool to London, a distance of 200 miles, in 4 hours, 26 minutes, 40 seconds?

4. Describe a simple method by which you could measure the velocity of a current of water.

5. What would be the length of a tunnel, through which a train passed in 4 minutes, when moving with a velocity of 36 miles per hour?

6. A person at Liverpool is carried round by the earth in its rotation, through a distance of about 15,000 miles per day. Express his velocity in miles per hour, and state how far the person moves each second.

EXAMINATION QUESTIONS.

1. What is meant by matter? Mention two or more properties which belong to all matter.
2. Name the five senses, and state in what portion of the body each is situated.
3. What is meant by saying that a body is transparent? Name several transparent bodies.
4. Describe the properties of iron, and explain the terms you use.
5. Compare the properties of glass with those of coal.
6. In what three states or conditions is matter found? Give several examples of each.
7. Mention a substance which is found to take at different times the condition of a solid, a liquid, and a gas. What causes it to change from one condition to another?
8. Describe the general properties of solid bodies.
9. Explain why it is easy to put your finger into a liquid, while it is difficult, or impossible, to force it into a solid body.
10. What is meant by the divisibility of a body? In what way might a piece of salt be divided into exceedingly minute portions? What name is given to the smallest portions of salt that could possibly be obtained?
11. What is meant by crystallisation? Mention some crystallised substances. For what purpose are they crystallised?
12. What is the hardest known solid? For what purposes is it employed on account of its hardness?
13. How is the gold which is used for coinage hardened? Give any other instance you know of other metals which are hardened by a similar process.
14. Explain the difference between the melting and the dissolving of a solid. Name some solids which are difficult to melt.
15. What changes occur in solid bodies when they are heated?
16. Explain why it is necessary that there should be one fixed standard of length in this country.
17. If one grain of gold can be drawn out into a wire 250 feet long, what weight of gold will be required to produce 3 miles of such a wire?

18. How would you express the volume of a solid body which measures 19 feet long, 2 feet wide, and 8 inches deep?

19. Find the weight of the air in a room which is 30 feet long, 18 feet broad, and 12 feet high, the weight of 100 cubic inches of air being 31 grains.

20. Find the total cost of painting the four walls of a room which is 30 feet long, 15 feet broad, and 15 feet high, at 1½d. per square foot.

21. What would be the cost of making an excavation 50 feet long, 30 feet broad, and 15 feet deep, at 9d. per cubic yard?

22. A sheet of iron, measuring 5 feet 6 inches long by 3 feet 4 inches broad, weighs 4 cwt.; find the weight of one square inch.

23. Describe the properties of a liquid.

24. What properties of liquids are not possessed by solids?

25. Compare the properties of water with those of ice.

26. Explain clearly what is meant by the statement that a solid has a definite, and a liquid an indefinite, shape.

27. What is cohesion? On what parts of a body does it act? Give some proof that cohesion acts in liquids.

28. What do you know of the transmission of pressure by liquids?

29. Why are reservoirs of water placed in elevated positions?

30. Write what you know of the force which causes the oil to rise in the wick of a lamp.

31. When mercury is placed in a glass tube, what is the form of the surface of the mercury? What would be the form of the surface of water in the same tube? Explain as far as you can the difference in the two cases.

32. When a quantity of liquid is placed in a vessel, what kind of surface does it assume? If a drop of the same liquid be placed on a flat surface, which it does not readily moisten, what form will it take?

33. Explain what is meant by the common expression that "water finds its own level," and give some illustrations of the fact.

34. Write all you know of the pressure of liquids.

35. Why do the walls of an embankment or reservoir increase in thickness towards the bottom?

36. Describe a simple experiment to prove that the pressure of a liquid on the sides of a vessel increases with the depth.

37. How would you proceed to prove that liquids exert an upward pressure on bodies which are immersed in them?

38. Explain the meaning of the term "specific gravity." How may the specific gravity of a liquid be ascertained?

39. What height would a column of water need to be, in order to balance a column of mercury 1½ inches high?

40. What is meant by the saying that "gold is nineteen times heavier than water"?

41. Explain why some bodies float in water and others do not. What is it which keeps the bodies afloat?

42. Why does a bar of iron sink in water, while the same bar made into the form of a boat floats?

43. Explain clearly why a ship floats in water. Why does she sink lower in the water when the cargo is taken on board?

44. A cubic foot of water weighs 62½ lbs., and the density of mercury is 13½ times that of water. Find the weight of one cubic inch of mercury.

45. If several liquids which do not mix with one another are contained in the same vessel, in what order will they arrange themselves?

46. Describe the changes which take place in a liquid as it is heated.

47. What is a thermometer? Describe its construction.

48. Why is mercury preferred for ordinary thermometers? Under what circumstances is mercury unsuitable?

49. If you dip your hand in warm water, and then hold it a short time in the air, your hand feels cold. Explain this.

50. What is the temperature of boiling water? Have all liquids the same temperature when they boil?

51. What is a vapour? how are vapours formed? how do they change when acted on by cold?

52. In what respects do liquids and gases agree, and in what respects do they differ?

53. Name three solids and three fluids. What are the differences between solids and fluids?

54. How may gases be converted into liquids? Name several gases which it is difficult to liquefy.

55. If I take a thin india-rubber ball filled with gas, and press on one part of it, the rest of the ball becomes more tightly stretched than before. Explain this, and state what property of gases it illustrates.

56. Describe some simple experiment to prove that the atmosphere exerts pressure on bodies.

57. What is the composition of the air? What pressure would the air exert on the whole surface of the water in a square vessel, the side of which measured six inches?

58. Why is a piece of paper not pressed hard against the table by the weight of the air above it?

59. What is the usual height of the column of mercury in a barometer? How does this height usually vary with the weather?

60. What is a vacuum? If some air made its way into the vacuum of a barometer, what effect would it have on the column of mercury?

61. State all the differences you know between a barometer containing mercury, and one containing water. Why is mercury usually preferred?

62. If a barometer were carried up in a balloon, how would the column of mercury be affected? Give reasons for your answer.

63. Describe the common bellows, and explain its action.

64. Describe the "sucker," and the manner in which it is made to adhere to a surface. Why does a sucker stick better on smooth than on rough surfaces?

65. What conditions are necessary in order that a liquid may be drawn off from one vessel into another by means of a siphon?

66. Describe the common water pump and explain its action.

67. Why will not a pump work if the distance between the surface of water in the well and the lower valve be greater than about 30 feet?

68. What is a piston? What is a valve? Mention some instruments in which those parts occur.

69. If an open flask be heated, and the mouth of it then plunged downwards below the surface of some water, describe and explain what occurs as the air cools.

70. What is wind? Explain the manner in which it is produced.

71. With what substances are balloons filled? Explain why a balloon rises in the air.

72. Explain why a closed bladder, which is only half full of air, swells out when laid for some time near a fire.

73. In what manner is pressure transmitted by a solid, a liquid, and a gas respectively?

74. If a piece of ice were placed in a vessel over a fire, describe as fully as you can the changes which would occur before the ice was fully converted into steam.

75. What general effect has heat on bodies? Give an example in the case of a liquid, a solid, and a gas respectively.

76. Explain what occurs as a substance passes from the solid to the liquid condition, and from the liquid to the solid condition.

77. Explain the meaning of the following terms:—Porous, compressible, ductile, malleable, opaque, and invisible. In each case mention one or more bodies having that character.

78. Why is a gas more easily compressed than either a solid or a liquid? What is meant by "compressibility"?

79. Explain clearly what occurs when a ball of solid india-rubber is dropped on to a hard smooth floor.

80. What is elasticity? Mention some bodies which are valuable on account of possessing this property in a high degree.

81. Describe an experiment to prove that air is elastic.

82. What is tenacity? how is it measured? Name a substance which has great tenacity.

83. Which is the most malleable metal? What use is made of the metal on account of that property?

84. Wrought iron when hot may be rolled out into sheets; what property does that prove it to possess? By what other processes might a lump of iron be made into the form of a sheet?

85. Lead is neither very malleable nor very ductile. Explain the meaning of this statement.

86. Explain with illustrations what is meant by cohesion, ductility, and brittleness.

87. How is time divided into years, months, and days?

88. Name the different contrivances that have been used for measuring time, and describe one of them.

89. Describe the sun-dial. Why is it not more commonly used for measuring time?

90. Explain why an ordinary pendulum clock loses time in summer and gains in winter.

91. Why do we speak of "Greenwich time"?

92. Explain the difference between a "lunar" month and a "calendar" month. How many lunar months are there in a year?

93. What is meant by a "leap year"? State the rule for finding what years are leap years.

94. What is meant by velocity? How is it measured?

95. If a horse travels 9 miles in 57 minutes, what is its velocity expressed in feet per second?

96. Explain how the velocity of a flying bird might be ascertained.

97. If a cannon ball moves 5 miles in 2 minutes, what is its velocity in miles per hour?

98. Two horses start from the same place in the same direction at the same time; one travels at the rate of 20 miles per hour, the other at the rate of 12 miles per hour. What distance will separate them 10 minutes after starting?

99. A train runs 24 miles in 32 minutes, how long will it take to go 40 miles? What is its velocity in miles per hour?

100. In what space of time would a balloon be carried 5 miles by a wind moving with a velocity of 14 miles per hour?

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